US006311264B1

(12) **United States Patent**
Boutaud et al.

(10) **Patent No.: US 6,311,264 B1**
(45) **Date of Patent: *Oct. 30, 2001**

(54) **DIGITAL SIGNAL PROCESSOR WITH WAIT STATE REGISTER**

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(73) Assignee: **Texas Instruments Incorporated**, Dallas, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/431,504**

(22) Filed: **Nov. 1, 1999**

Related U.S. Application Data

(62) Division of application No. 09/360,488, filed on Jul. 23, 1999, which is a division of application No. 08/906,863, filed on Aug. 6, 1997, now Pat. No. 5,946,483, which is a division of application No. 08/293,259, filed on Aug. 19, 1994, now Pat. No. 5,907,714, and a continuation of application No. 07/967,942, filed on Oct. 28, 1992, now abandoned, which is a continuation of application No. 07/347,967, filed on May 4, 1989, now abandoned.

(51) **Int. Cl.**[7] **G06F 15/00**
(52) **U.S. Cl.** **712/38**; 710/16; 713/401
(58) **Field of Search** 713/501, 502, 713/600, 401; 712/38, 43; 710/130, 16

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"DSP96001", Motorola, 1988, pp. 1, 2, 6, 9, 10.
Second–Generation TMS320 User's Guide, Texas Instruments, pp. 6–10–26,Dec. 1987.

Primary Examiner—Larry D. Donaghue
(74) *Attorney, Agent, or Firm*—Lawrence J. Bassuk; Frederick J. Telecky

(57) **ABSTRACT**

A data processing device is used with peripheral devices having addressees and differing communication response periods. The data processing device includes a digital processor adapted for selecting different ones of the peripheral devices by asserting addresses of each selected peripheral device. Addressable programmable registers hold wait state values representative of distinct numbers of wait states corresponding to different address ranges. Circuitry responsive to an asserted address to the peripheral devices asserted by the digital processor generates the number of wait states represented by the value held in one of the addressable programmable registers corresponding to the one of the address ranges in which the asserted address occurs, thereby accommodating the differing communication response periods of the peripheral devices.

8 Claims, 18 Drawing Sheets

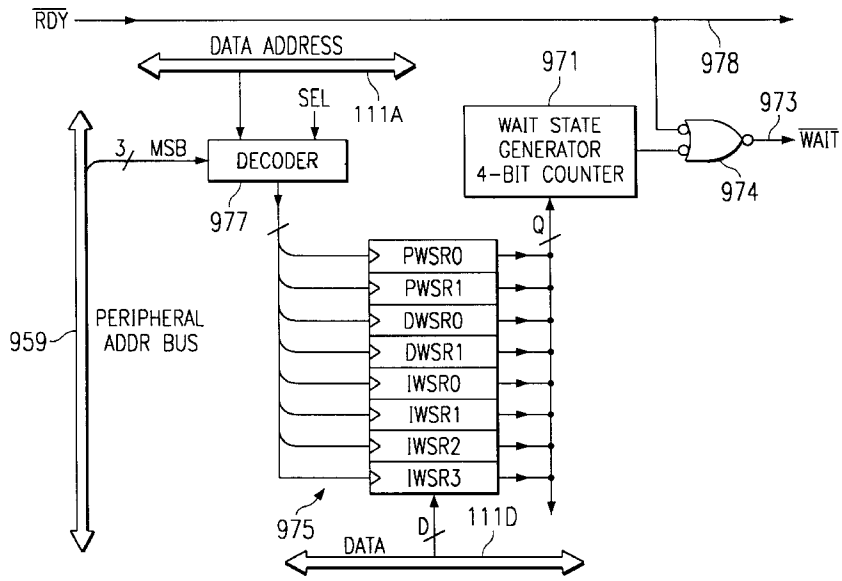

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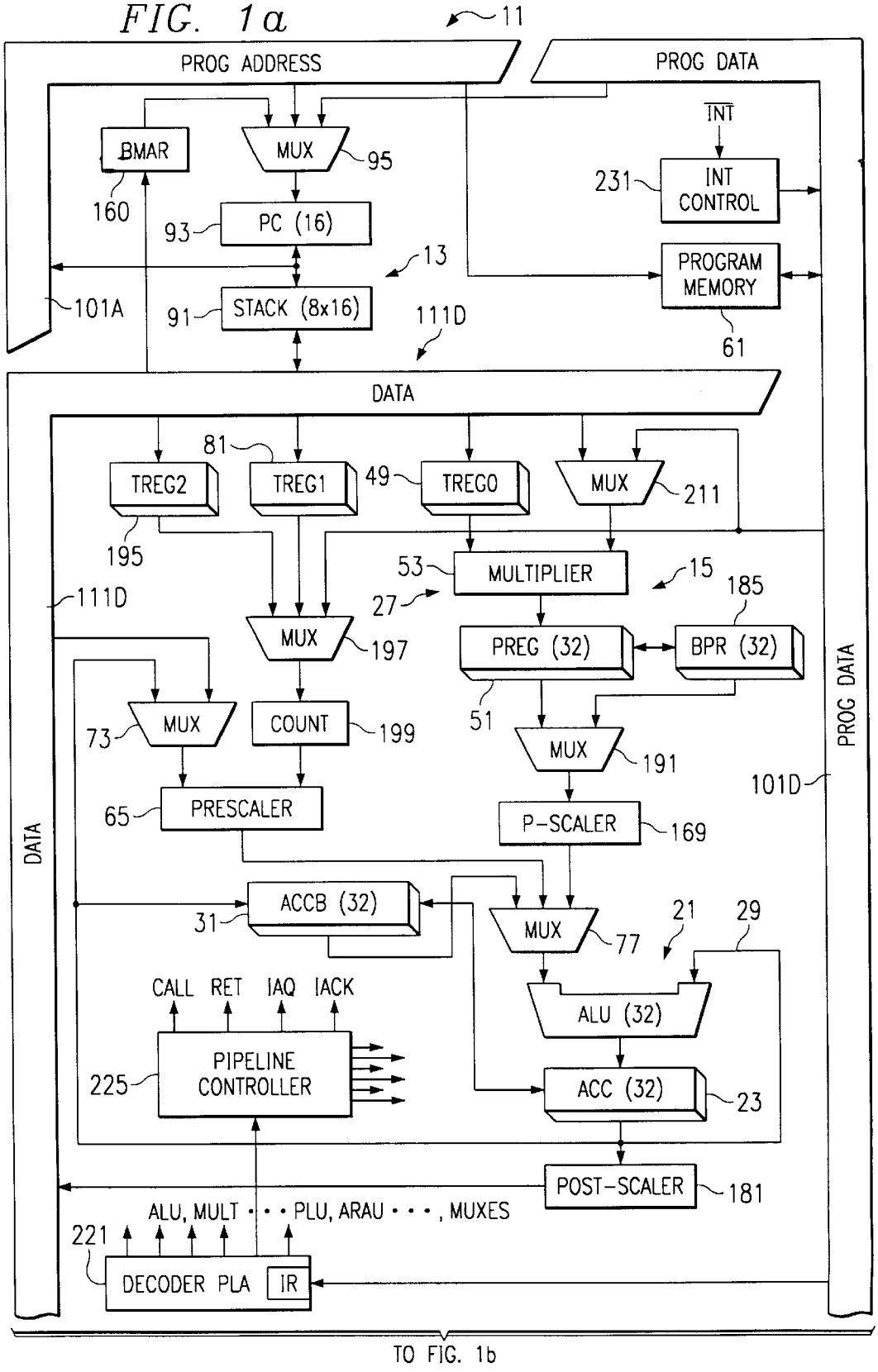
FIG. 1a


11
PROG ADDRESS
PROG DATA
INT
BMAR
MUX
95
160
231
INT CONTROL
93
PC (16)
13
PROGRAM MEMORY
101A
91
STACK (8x16)
111D
61
DATA
81
TREG2
TREG1
49
TREG0
MUX
211
195
53
MULTIPLIER
15
185
111D
27
MUX
197
PREG (32)
BPR (32)
73
MUX
COUNT
199
51
MUX
191
101D
65
PRESCALER
P-SCALER
169
DATA
PROG DATA
ACCB (32)
31
MUX
77
21
29
CALL RET IAQ IACK
ALU (32)
PIPELINE CONTROLLER
225
ACC (32)
23
POST-SCALER
181
ALU, MULT • • • PLU, ARAU • • • , MUXES
221
DECODER PLA
IR
TO FIG. 1b

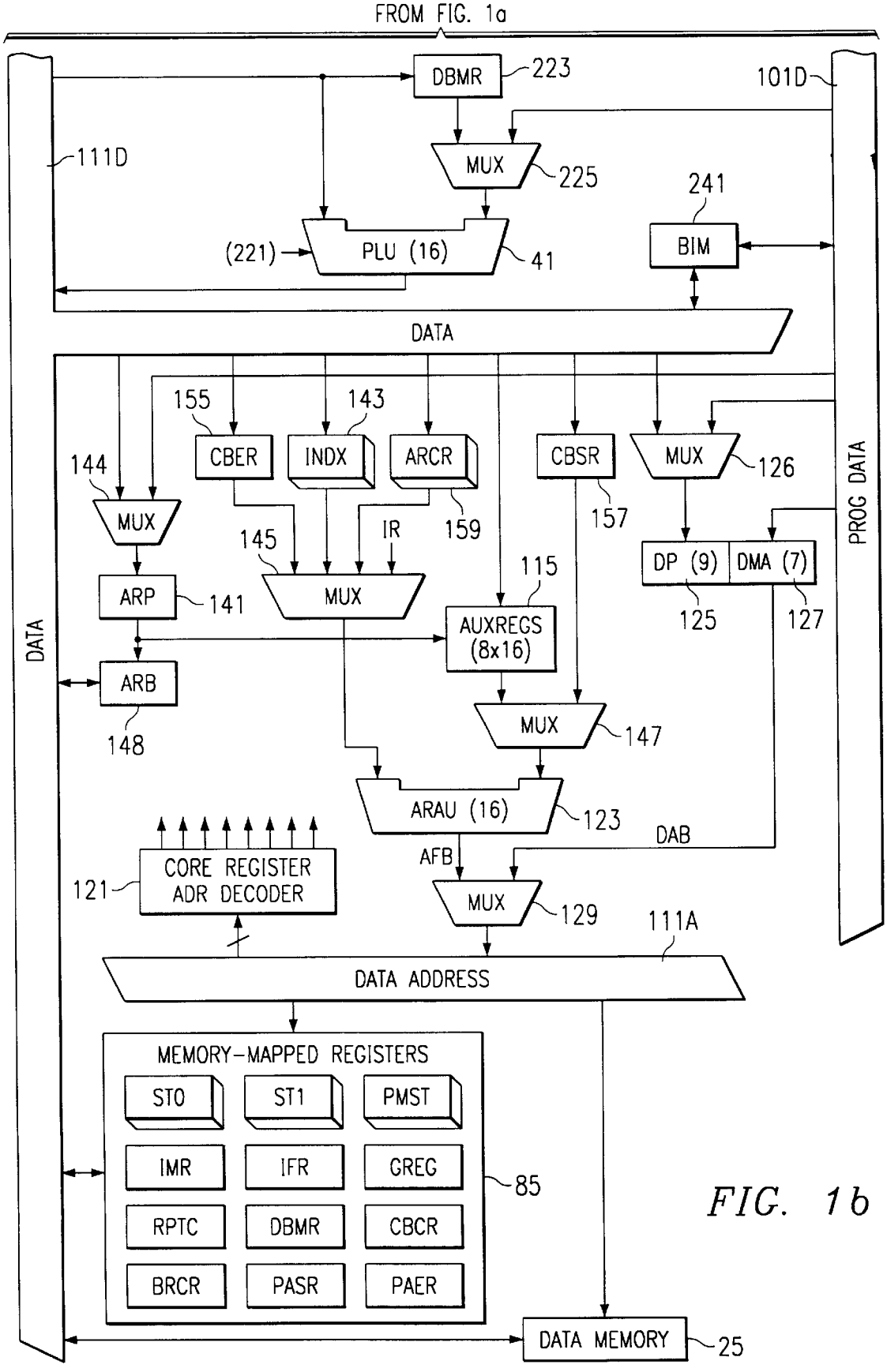

FROM FIG. 1a
DBMR
223
101D
111D
MUX
225
241
(221)
PLU (16)
41
BIM
DATA
155
143
144
CBER
INDX
ARCR
CBSR
MUX
126
MUX
145
IR
159
157
PROG DATA
DP (9)
DMA (7)
115
ARP
141
MUX
AUXREGS (8x16)
125
127
DATA
ARB
148
MUX
147
ARAU (16)
123
DAB
AFB
CORE REGISTER ADR DECODER
121
MUX
129
111A
DATA ADDRESS
MEMORY-MAPPED REGISTERS
ST0
ST1
PMST
IMR
IFR
GREG
85
RPTC
DBMR
CBCR
BRCR
PASR
PAER
DATA MEMORY
25

FIG. 1b

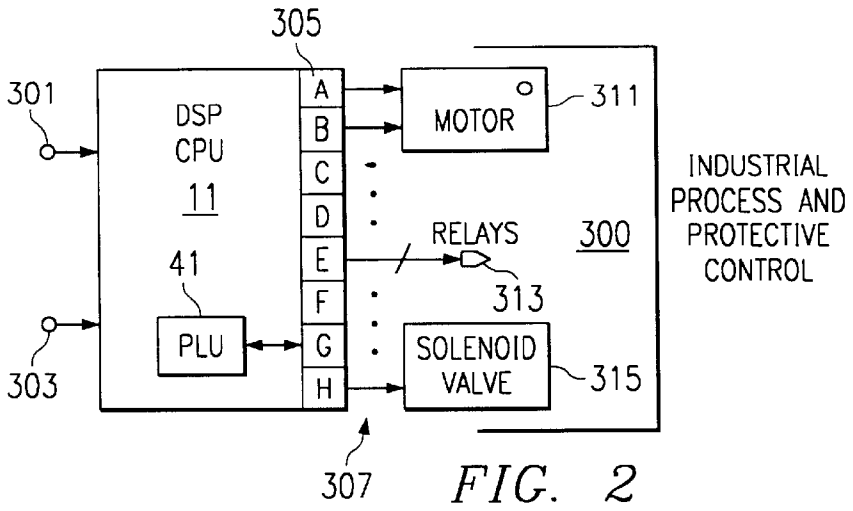

305
301
DSP
CPU
11
41
PLU
303
A
B
C
D
E
F
G
H
MOTOR
311
RELAYS
300
313
SOLENOID
VALVE
315
INDUSTRIAL
PROCESS AND
PROTECTIVE
CONTROL
307

FIG. 2

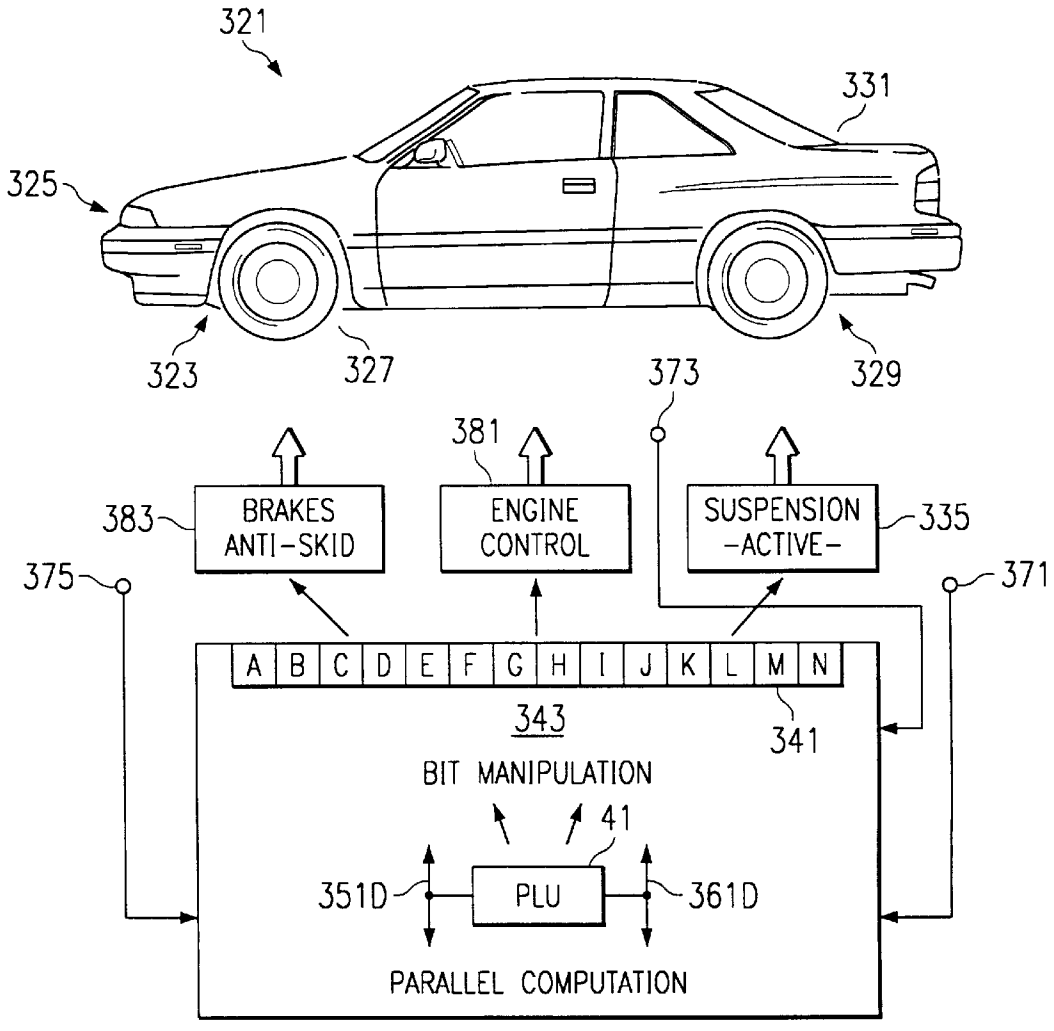

321
331
325
323
327
373
329
381
383
BRAKES
ANTI-SKID
ENGINE
CONTROL
SUSPENSION
-ACTIVE-
335
375
371
A B C D E F G H I J K L M N
343
341
BIT MANIPULATION
41
351D
PLU
361D
PARALLEL COMPUTATION

FIG. 3

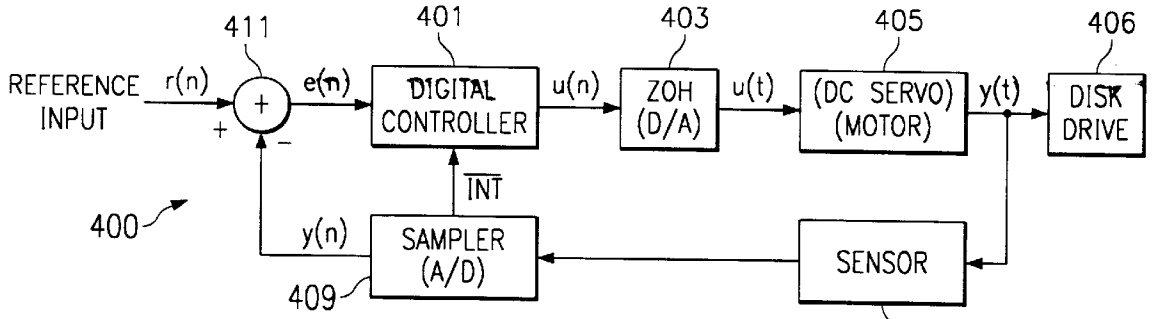


FIG. 4

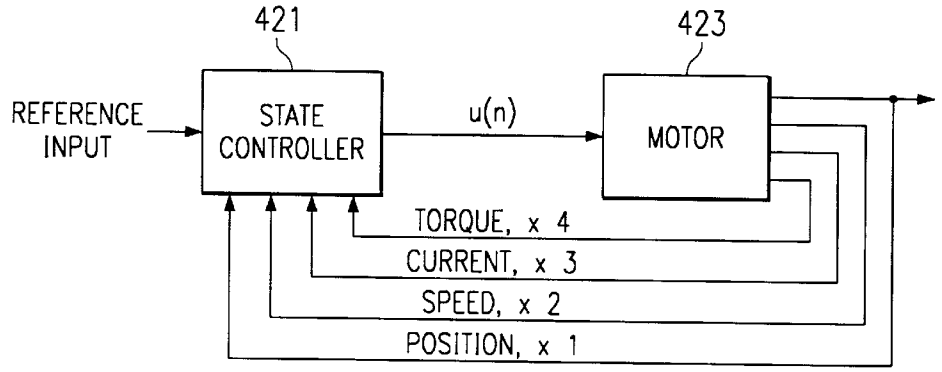


FIG. 5

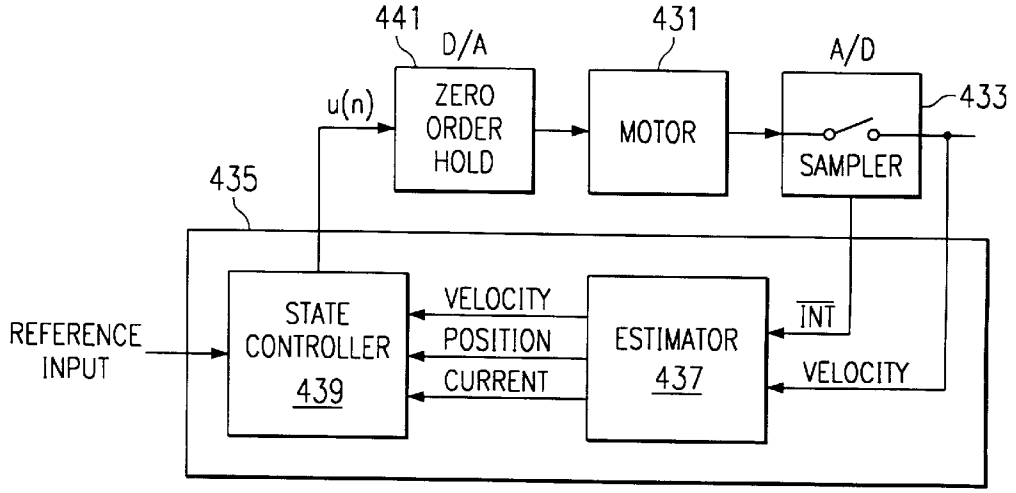


FIG. 6

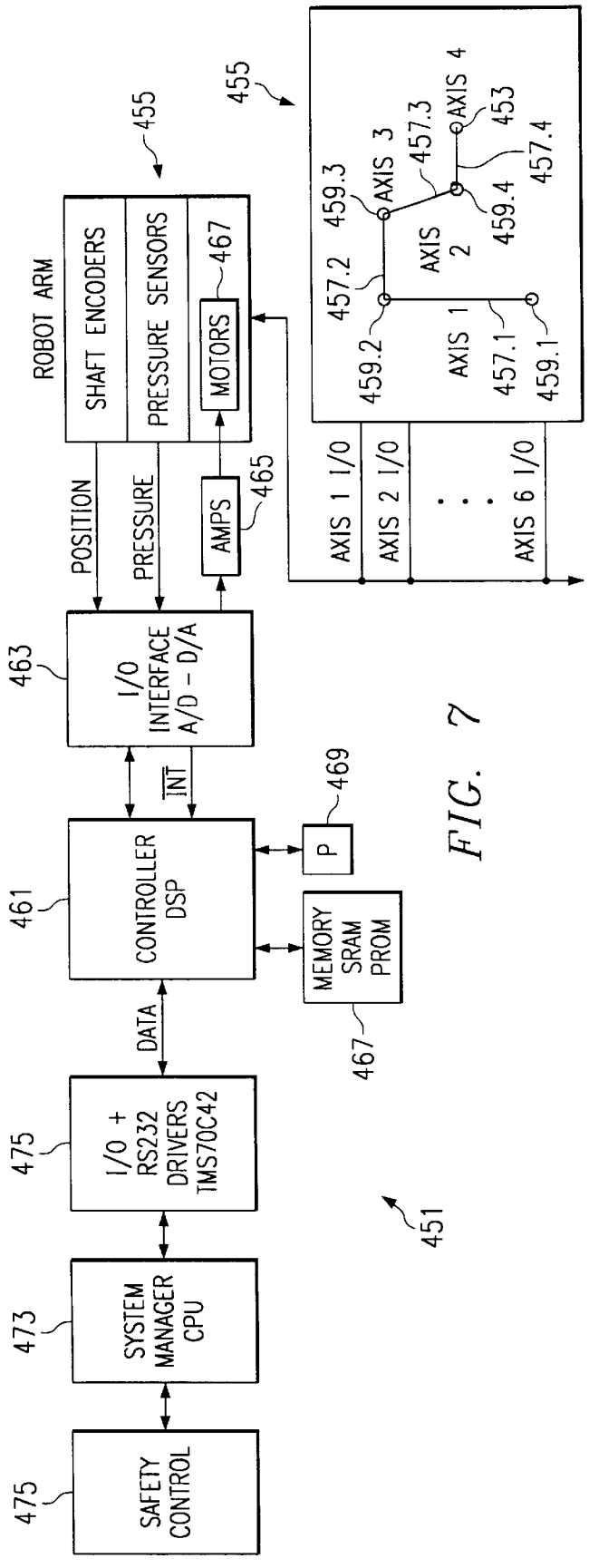

ROBOT ARM
SHAFT ENCODERS
PRESSURE SENSORS
MOTORS
467
455
455
POSITION
PRESSURE
AMPS
465
463
I/O INTERFACE A/D - D/A
INT
461
CONTROLLER DSP
P
469
MEMORY SRAM PROM
467
DATA
475
I/O + RS232 DRIVERS TMS70C42
473
SYSTEM MANAGER CPU
475
SAFETY CONTROL
451
AXIS 1 I/O
AXIS 2 I/O
AXIS 6 I/O
AXIS 1
AXIS 2
AXIS 3
AXIS 4
453
457.1
457.2
457.3
457.4
459.1
459.2
459.3
459.4

FIG. 7

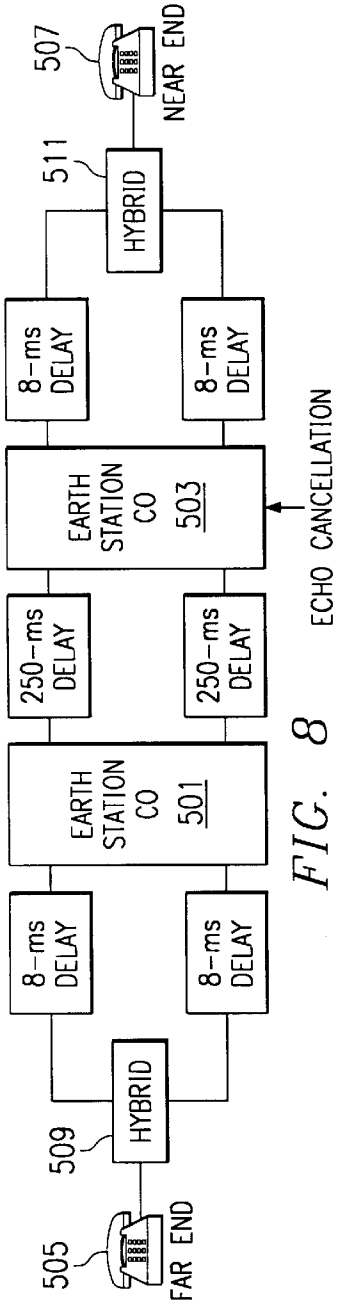

507
NEAR END
511
HYBRID
8-ms DELAY
8-ms DELAY
EARTH STATION CO 503
250-ms DELAY
250-ms DELAY
EARTH STATION CO 501
8-ms DELAY
8-ms DELAY
509
HYBRID
505
FAR END
ECHO CANCELLATION

FIG. 8

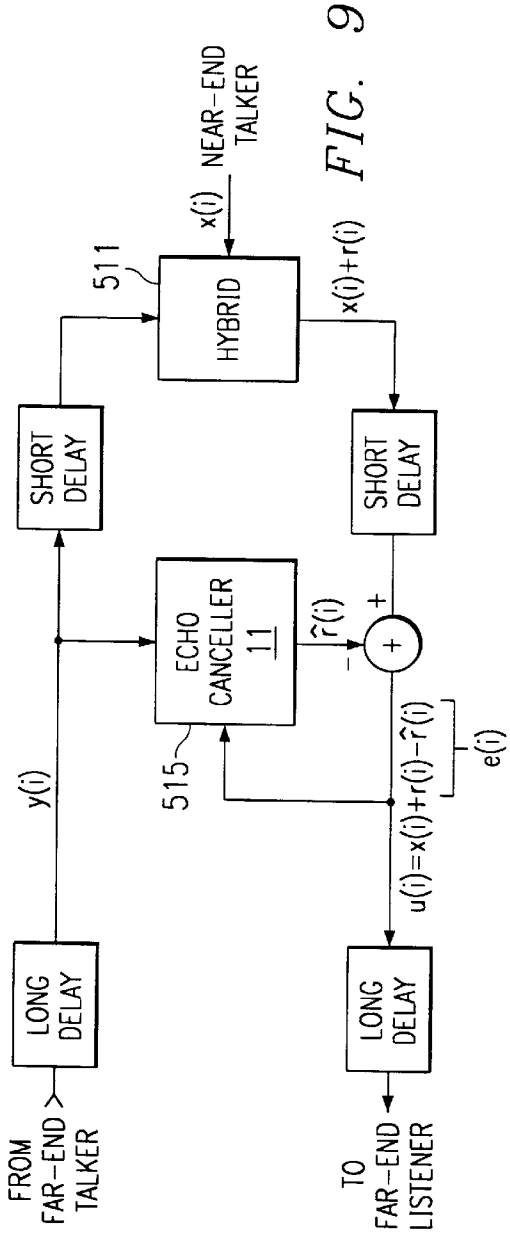

FROM FAR-END TALKER
LONG DELAY
y(i)
SHORT DELAY
511
HYBRID
x(i) NEAR-END TALKER
x(i)+r(i)
SHORT DELAY
ECHO CANCELLER 11
515
r̂(i)
e(i)
u(i)=x(i)+r(i)-r̂(i)
LONG DELAY
TO FAR-END LISTENER

FIG. 9

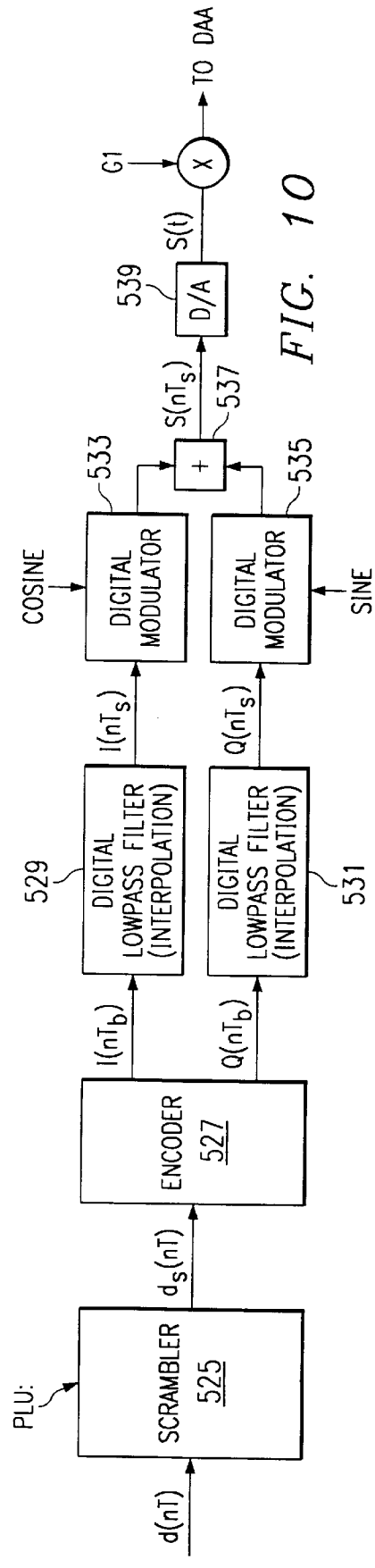

PLU:
SCRAMBLER 525
d(nT)
d_S(nT)
ENCODER 527
I(nT_b)
Q(nT_b)
529
DIGITAL LOWPASS FILTER (INTERPOLATION)
531
DIGITAL LOWPASS FILTER (INTERPOLATION)
I(nT_S)
Q(nT_S)
COSINE
533
DIGITAL MODULATOR
535
DIGITAL MODULATOR
SINE
S(nT_S)
537
539
D/A
S(t)
G1
TO DAA

FIG. 10

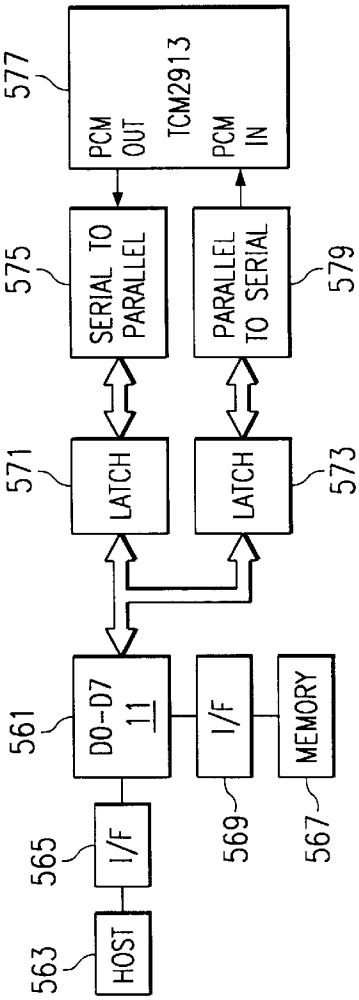


FIG. 13

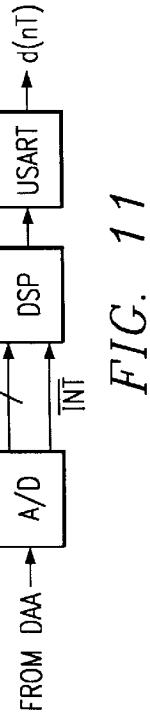


FIG. 11

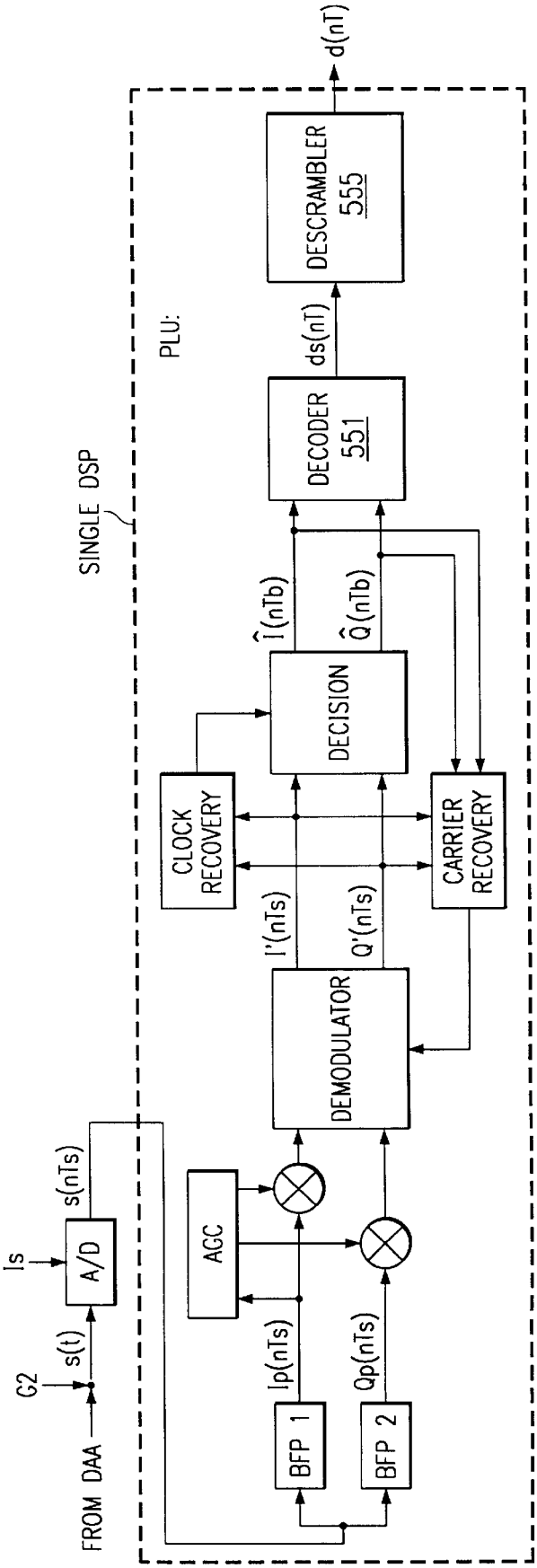


FIG. 12

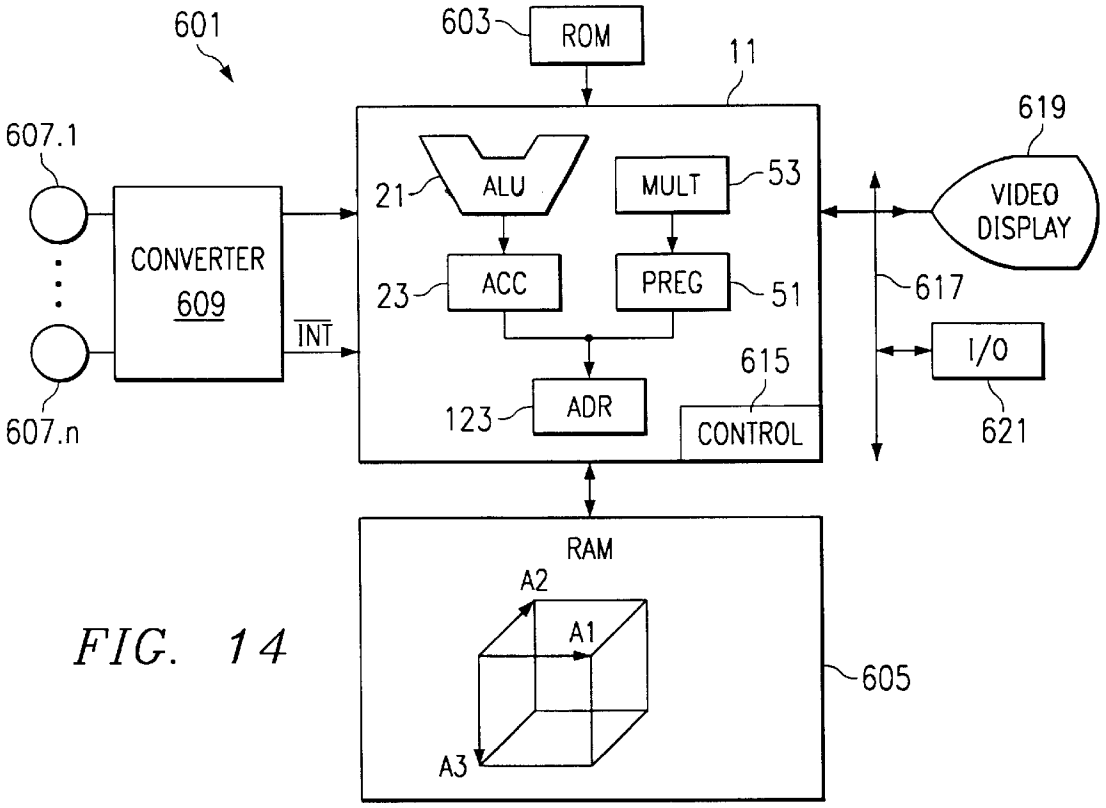

601
603
ROM
11
619
607.1
21
ALU
MULT
53
VIDEO DISPLAY
CONVERTER 609
23
ACC
PREG
51
617
INT
I/O
615
123
ADR
CONTROL
621
607.n
RAM
A2
A1
A3
605

FIG. 14

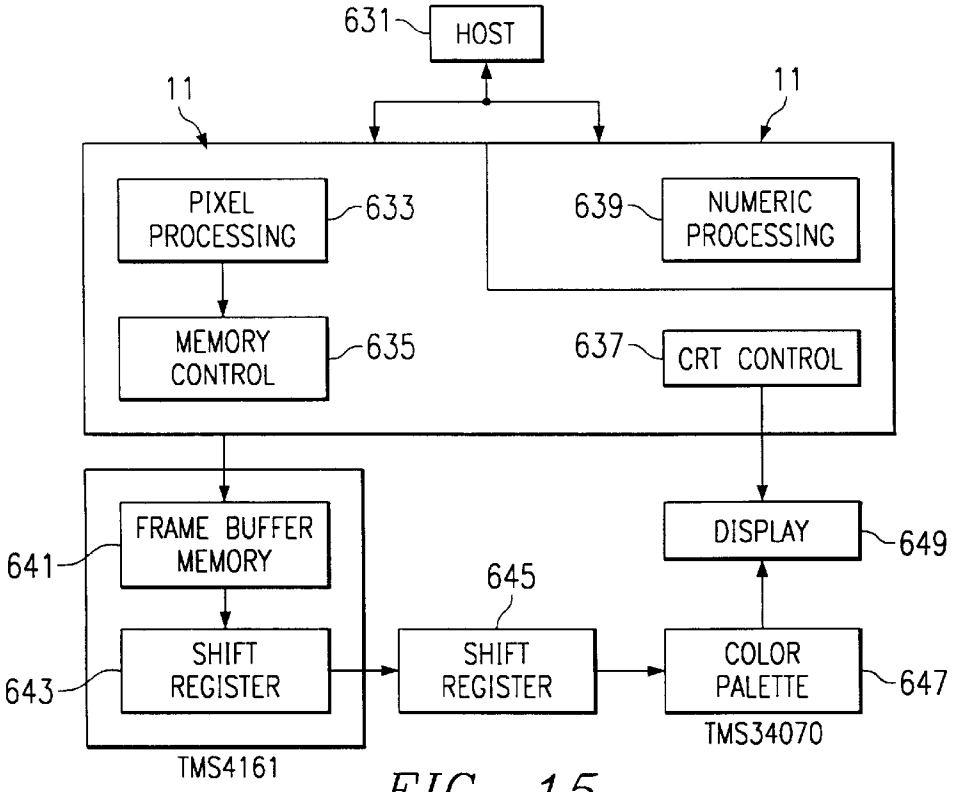

631
HOST
11
11
PIXEL PROCESSING
633
639
NUMERIC PROCESSING
MEMORY CONTROL
635
637
CRT CONTROL
FRAME BUFFER MEMORY
641
DISPLAY
649
645
643
SHIFT REGISTER
SHIFT REGISTER
COLOR PALETTE
647
TMS4161
TMS34070

FIG. 15

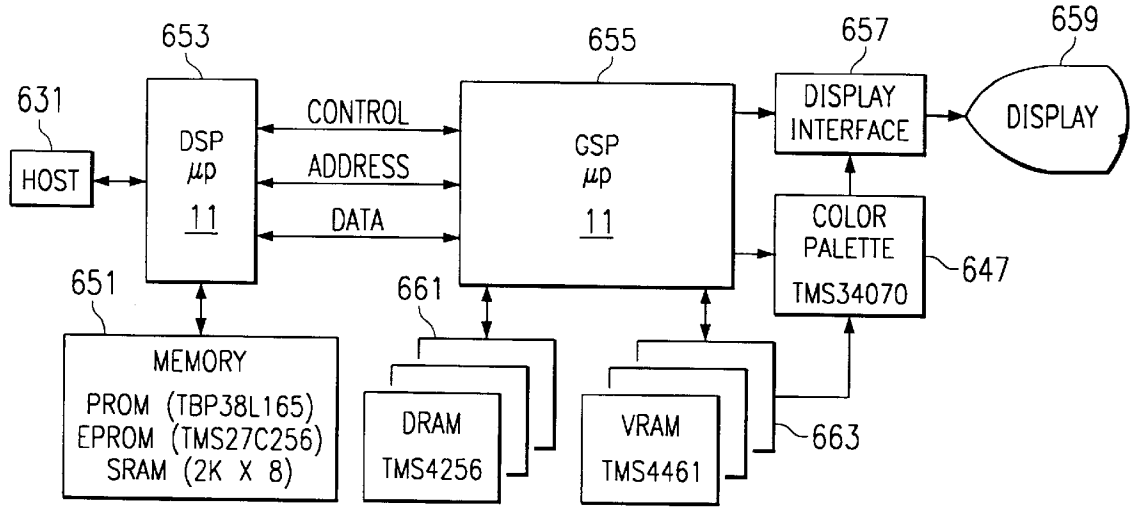

653
655
657
659
631
DSP
μp
11
CONTROL
ADDRESS
DATA
GSP
μp
11
DISPLAY INTERFACE
DISPLAY
HOST
COLOR PALETTE TMS34070
647
651
661
MEMORY
PROM (TBP38L165)
EPROM (TMS27C256)
SRAM (2K X 8)
DRAM TMS4256
VRAM TMS4461
663

FIG. 16

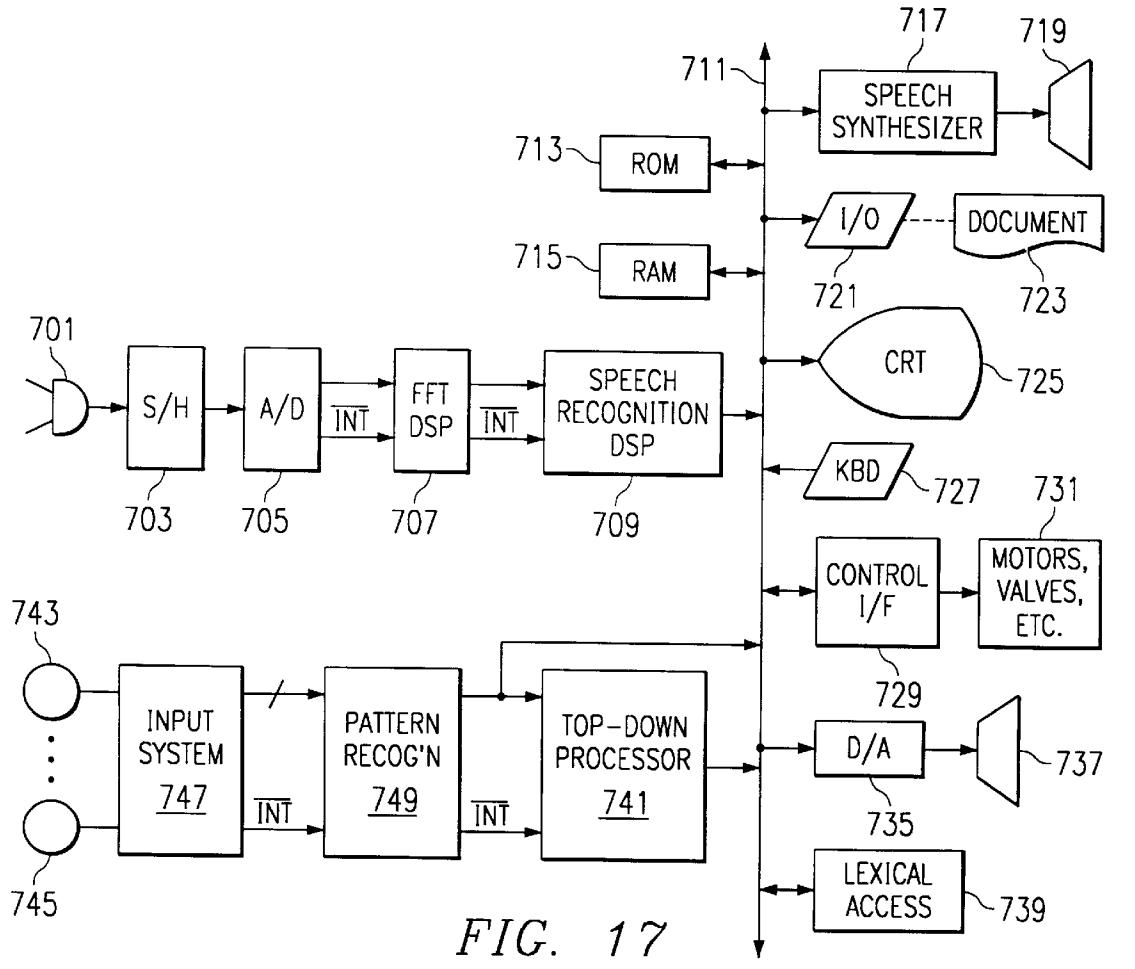

717
719
711
SPEECH SYNTHESIZER
713
ROM
I/O
DOCUMENT
715
RAM
721
723
701
CRT
725
S/H
A/D
INT
FFT DSP
INT
SPEECH RECOGNITION DSP
KBD
727
731
703
705
707
709
CONTROL I/F
MOTORS, VALVES, ETC.
743
729
INPUT SYSTEM 747
INT
PATTERN RECOG'N 749
INT
TOP-DOWN PROCESSOR 741
D/A
737
735
745
LEXICAL ACCESS
739

FIG. 17

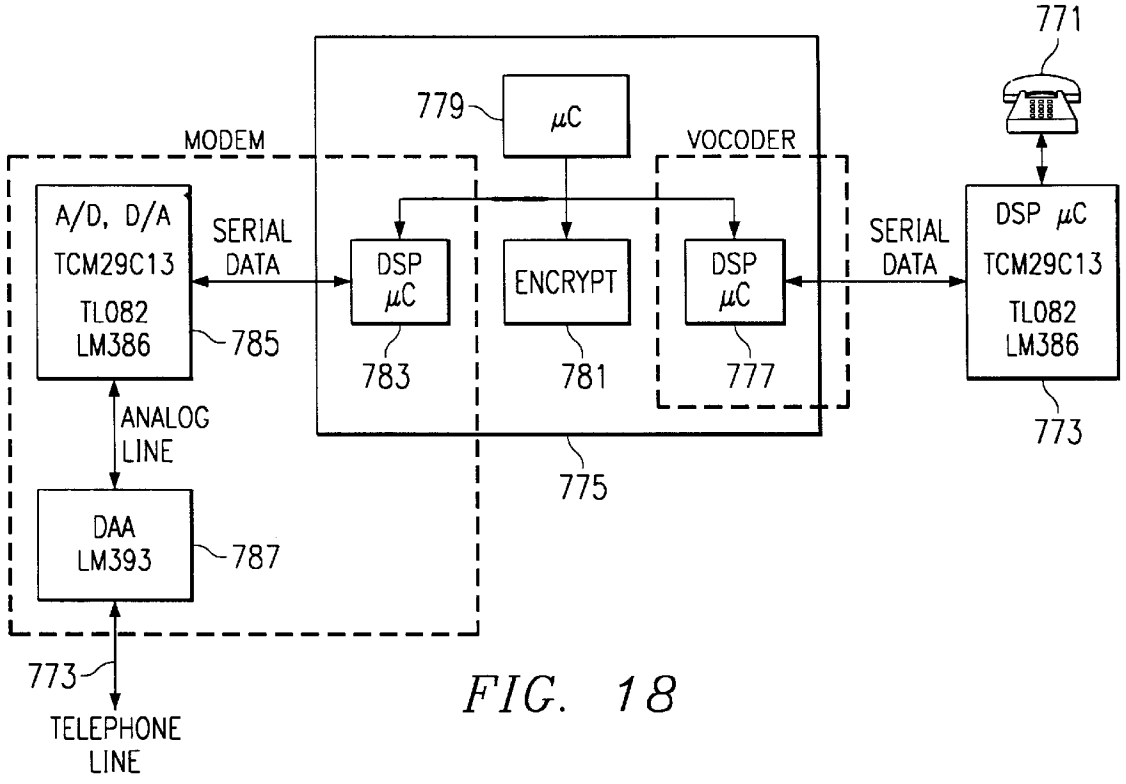


FIG. 18

FIG. 19a

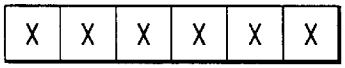


FIG. 19b

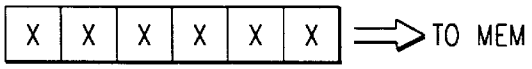


FIG. 19c

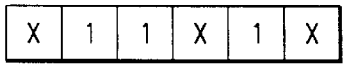


FIG 19d

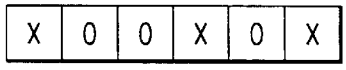


FIG. 19e

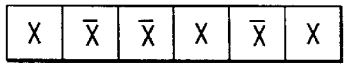


FIG. 19f

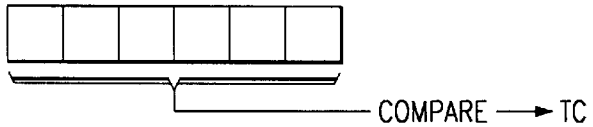
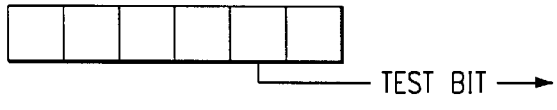


FIG. 19g



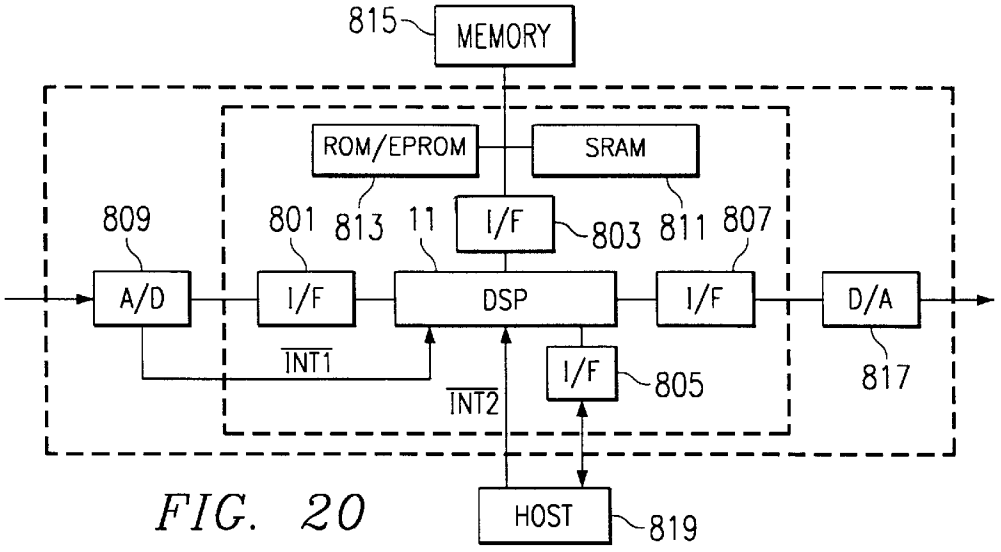

815
MEMORY
ROM/EPROM
SRAM
809
801
813
11
I/F
803
811
807
A/D
I/F
DSP
I/F
D/A
INT1
I/F
805
817
INT2
HOST
819

FIG. 20

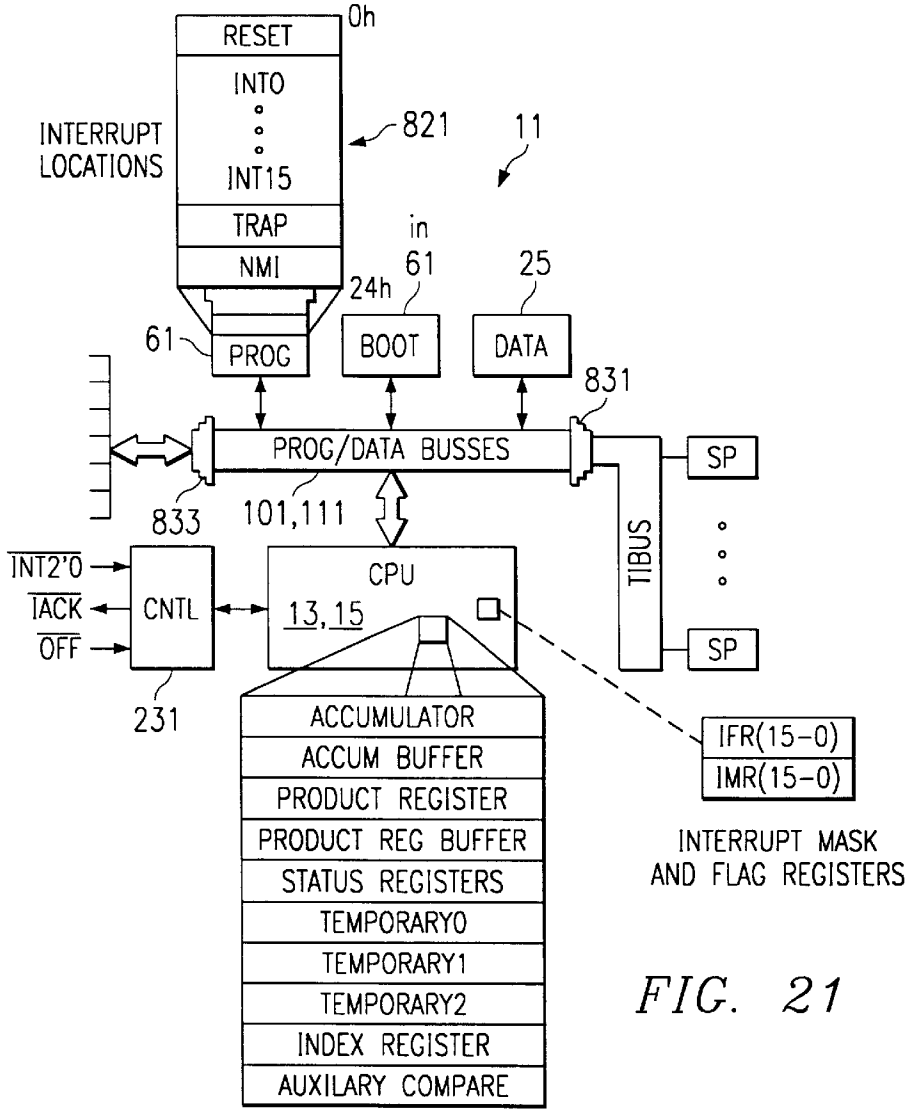

0h
RESET
INTO
INT15
INTERRUPT LOCATIONS
821
11
TRAP
NMI
in
61
24h
25
61
PROG
BOOT
DATA
831
PROG/DATA BUSSES
SP
833
101,111
TIBUS
INT2'0
IACK
OFF
CNTL
CPU
13,15
SP
231
ACCUMULATOR
ACCUM BUFFER
PRODUCT REGISTER
PRODUCT REG BUFFER
STATUS REGISTERS
TEMPORARY0
TEMPORARY1
TEMPORARY2
INDEX REGISTER
AUXILARY COMPARE
IFR(15-0)
IMR(15-0)
INTERRUPT MASK AND FLAG REGISTERS

FIG. 21

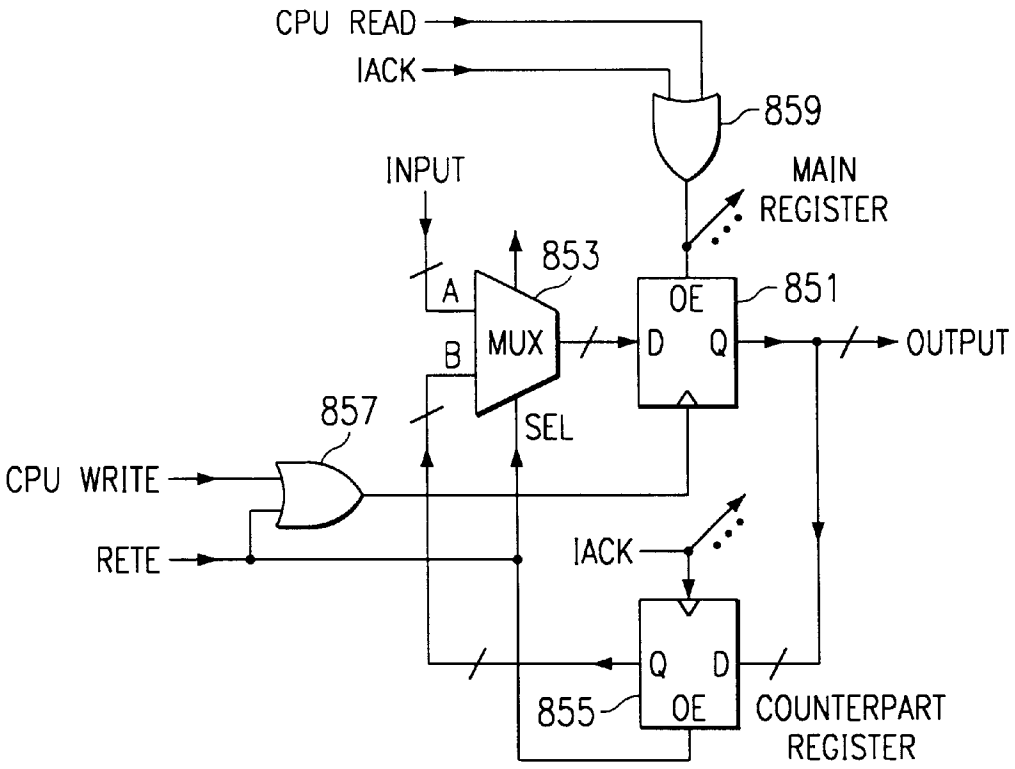

CPU READ
IACK
859
INPUT
MAIN
REGISTER
853
A
B
MUX
SEL
OE
D Q
851
OUTPUT
857
CPU WRITE
RETE
IACK
Q D
OE
855
COUNTERPART
REGISTER

FIG. 22

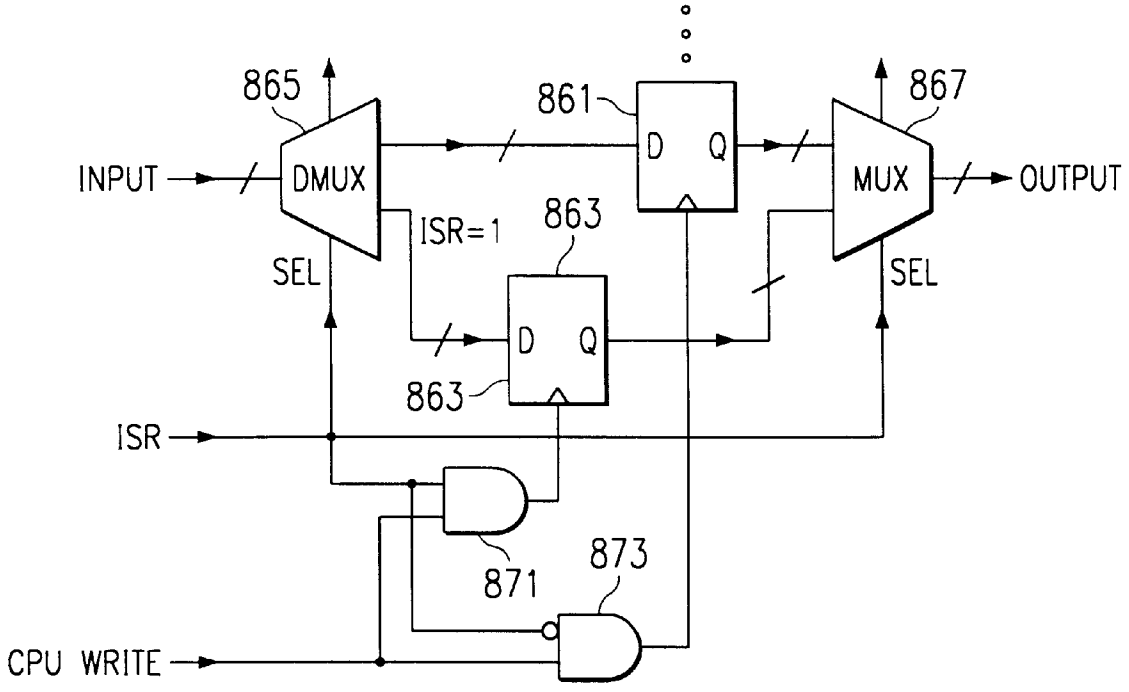

865
861
867
INPUT
DMUX
D Q
MUX
OUTPUT
ISR=1
863
SEL
SEL
D Q
863
ISR
871
873
CPU WRITE

FIG. 23

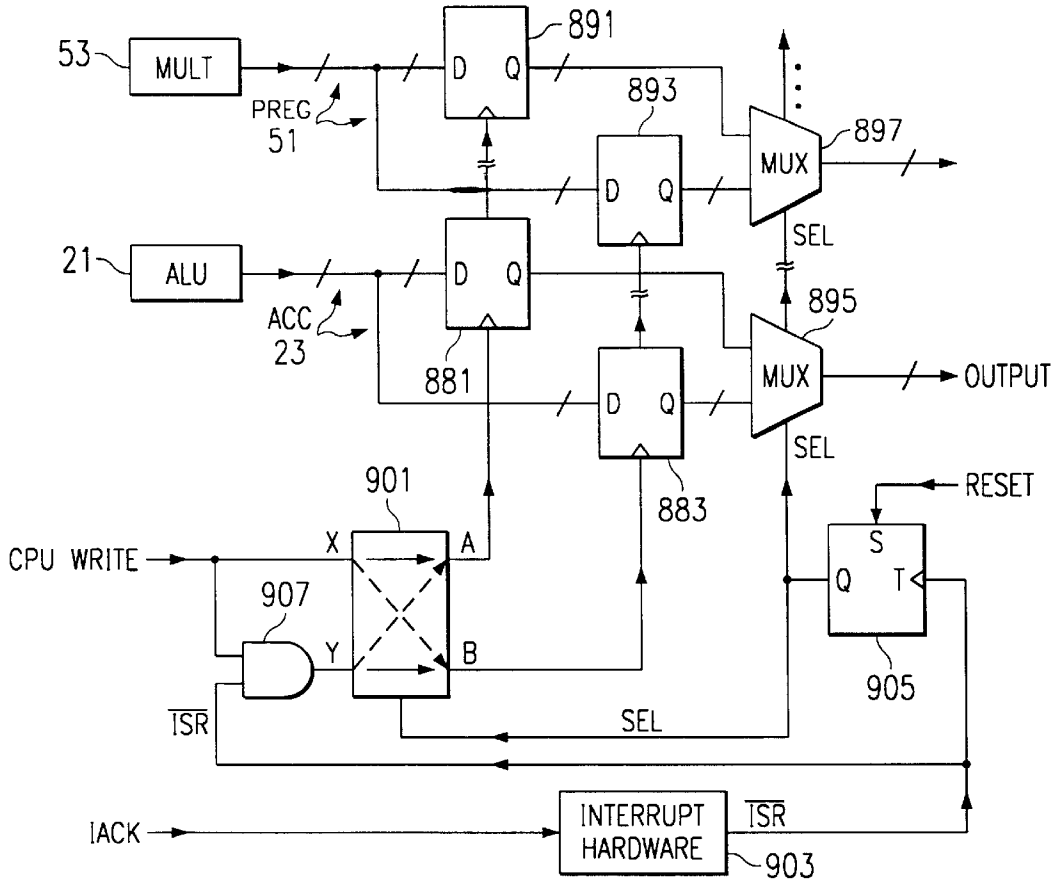


FIG. 24

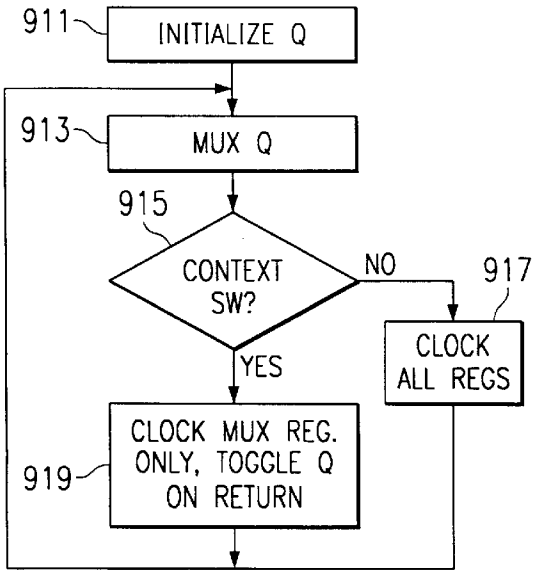


FIG. 25

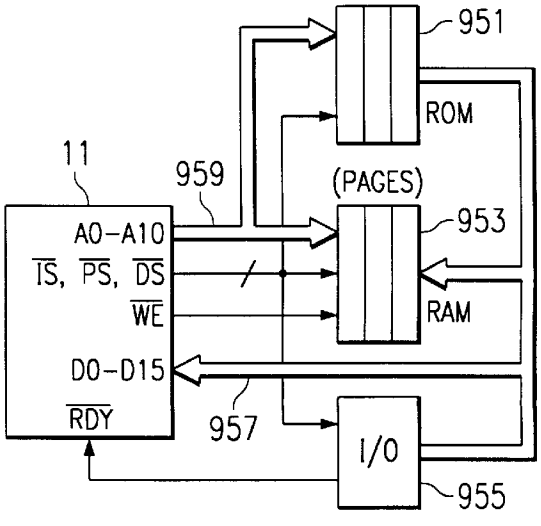


FIG. 26

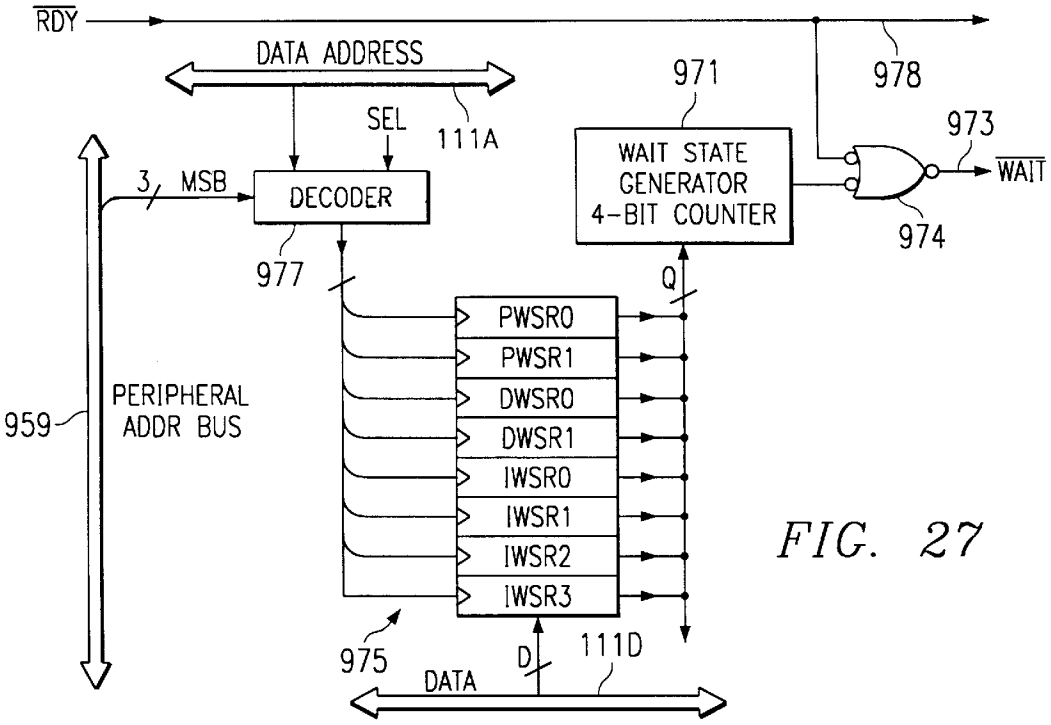

RDY
DATA ADDRESS
971
978
SEL
111A
973
WAIT STATE GENERATOR 4-BIT COUNTER
WAIT
3
MSB
DECODER
974
977
Q
PWSR0
PWSR1
DWSR0
DWSR1
IWSR0
IWSR1
IWSR2
IWSR3
959
PERIPHERAL ADDR BUS
975
D
111D
DATA

FIG. 27

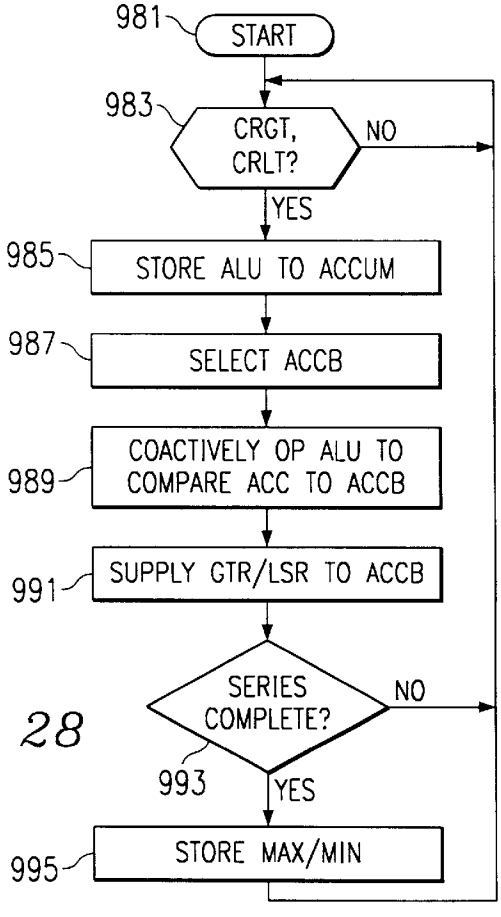

981
START
983
CRGT, CRLT?
NO
YES
985
STORE ALU TO ACCUM
987
SELECT ACCB
989
COACTIVELY OP ALU TO COMPARE ACC TO ACCB
991
SUPPLY GTR/LSR TO ACCB
SERIES COMPLETE?
NO
993
YES
995
STORE MAX/MIN

FIG. 28

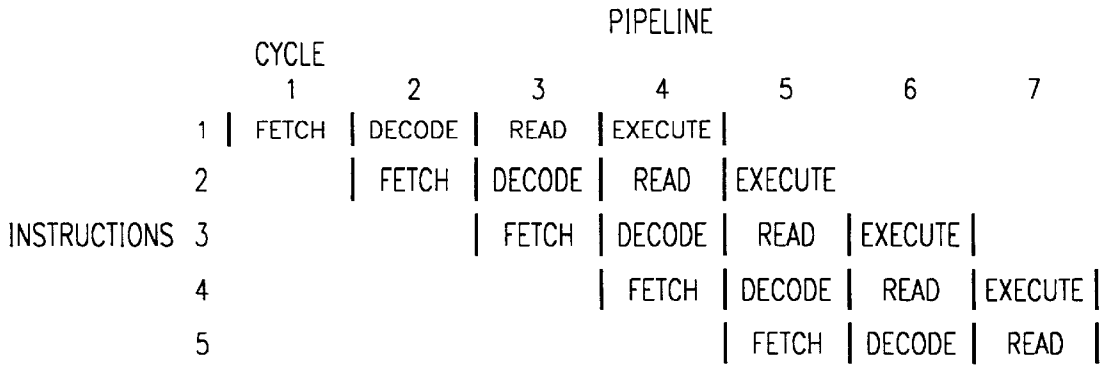


FIG. 29

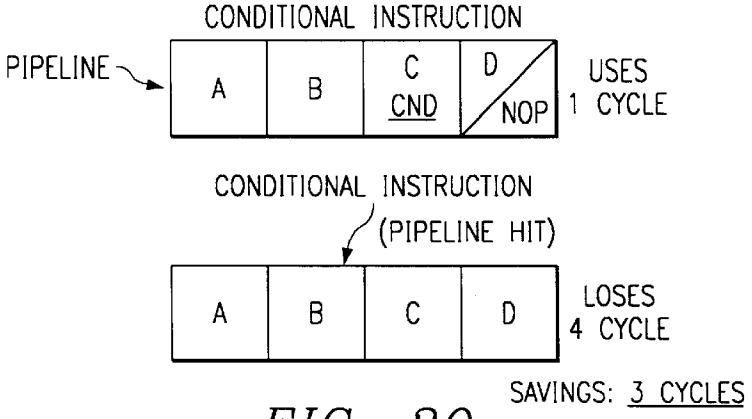


FIG. 30

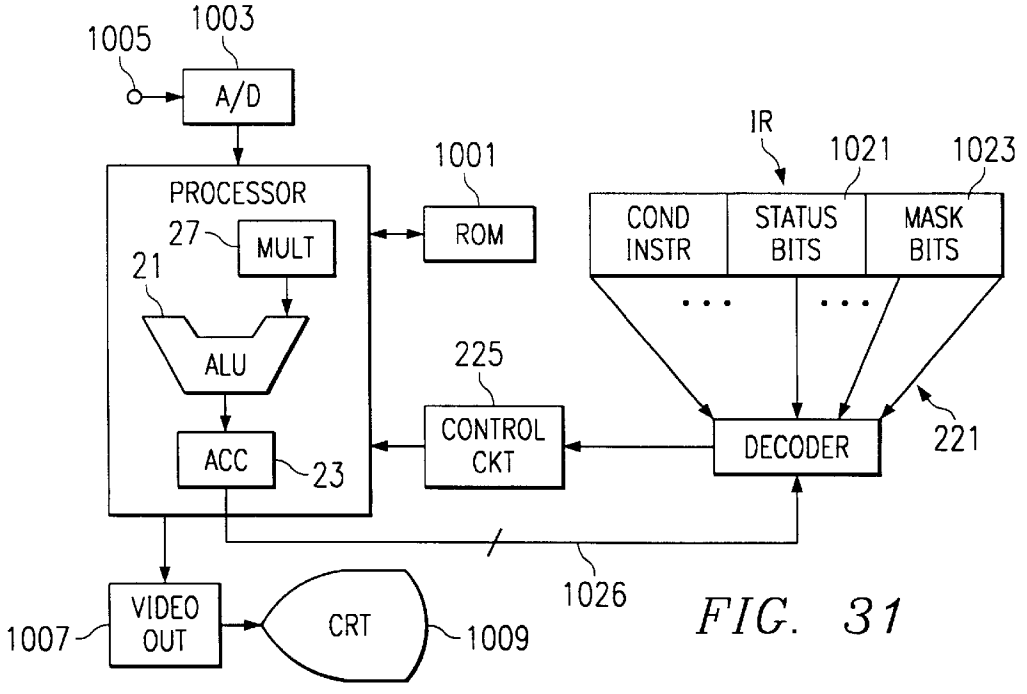


FIG. 31

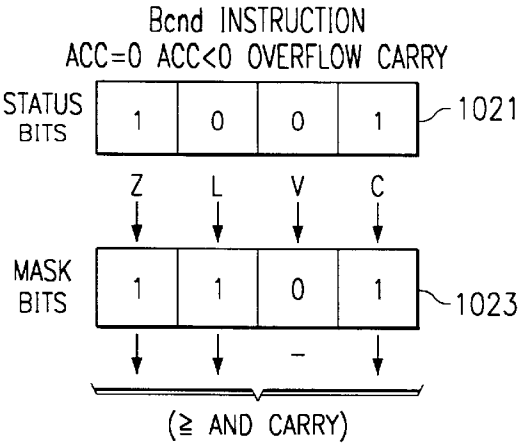


FIG. 32

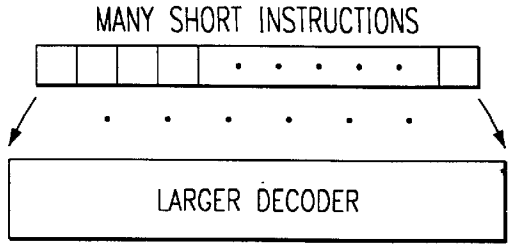


FIG. 33

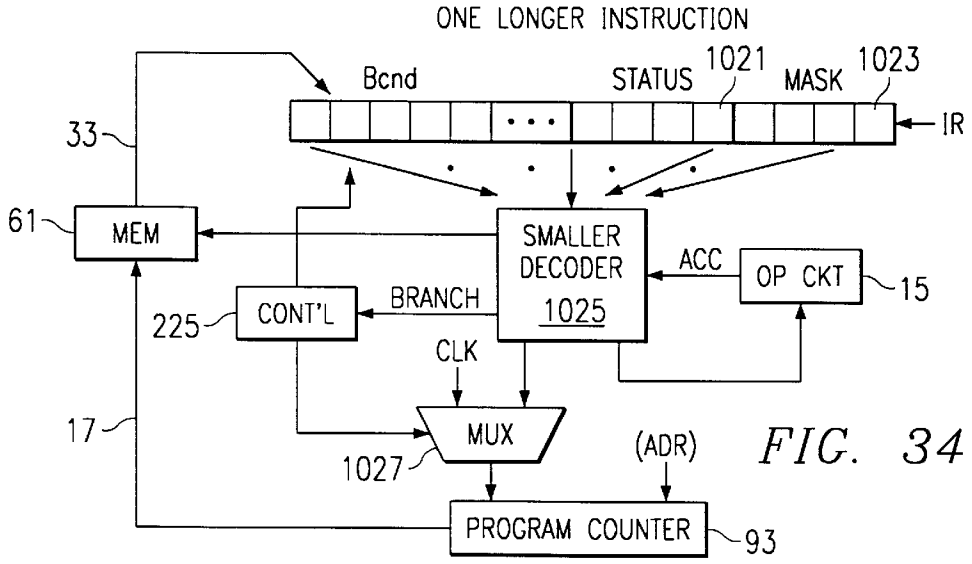


FIG. 34

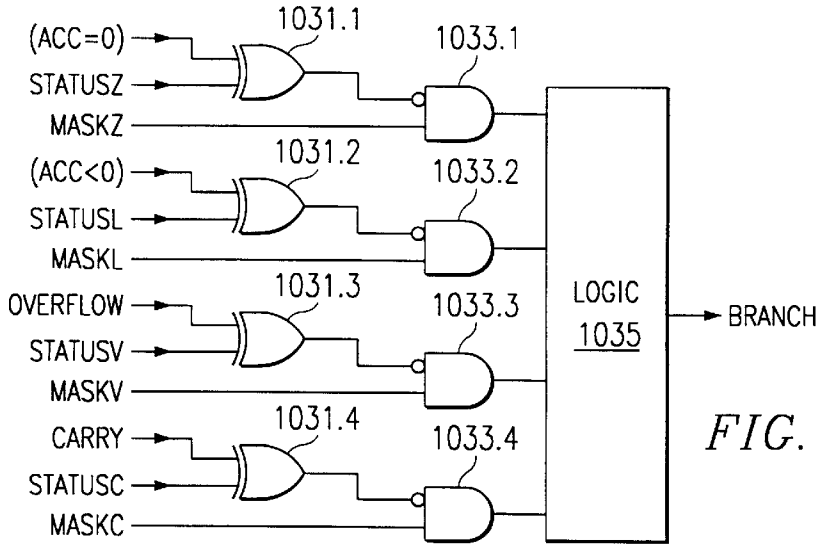


FIG. 35

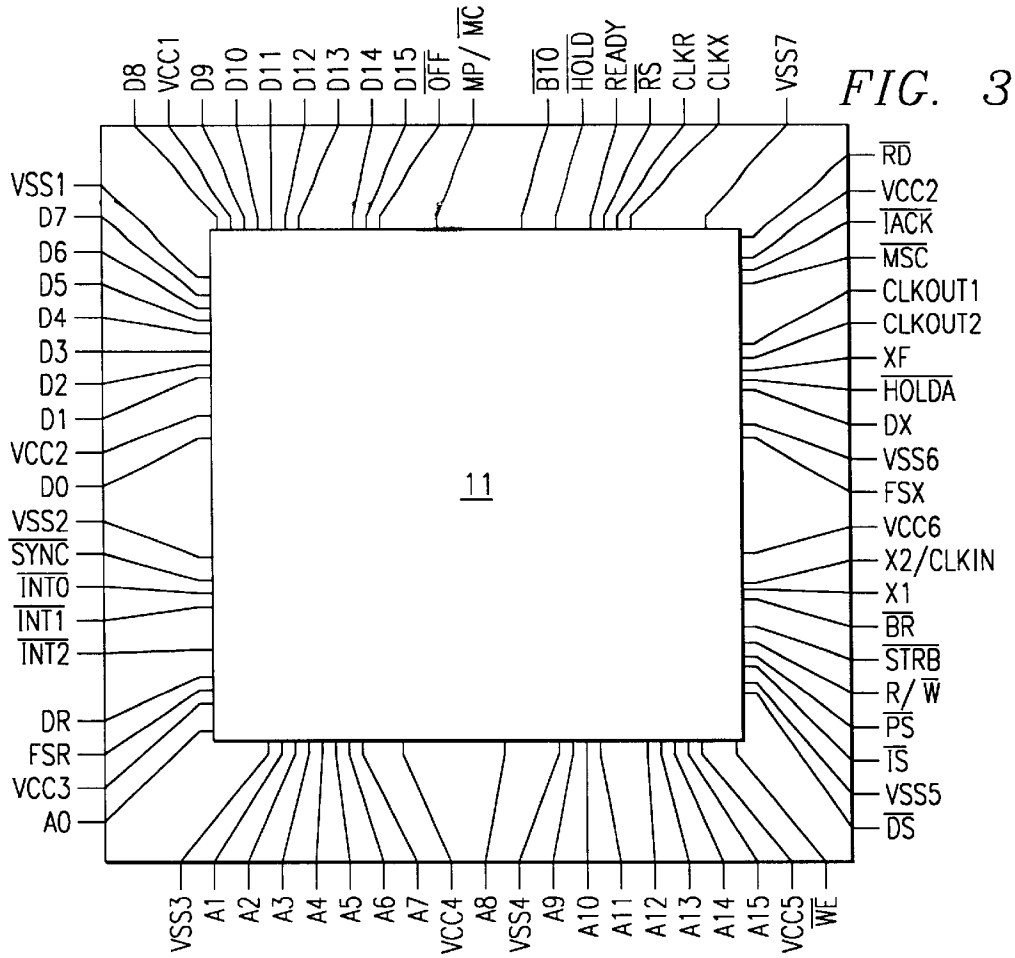


FIG. 36

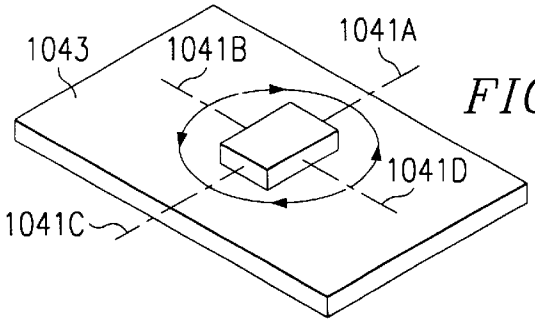


FIG. 37

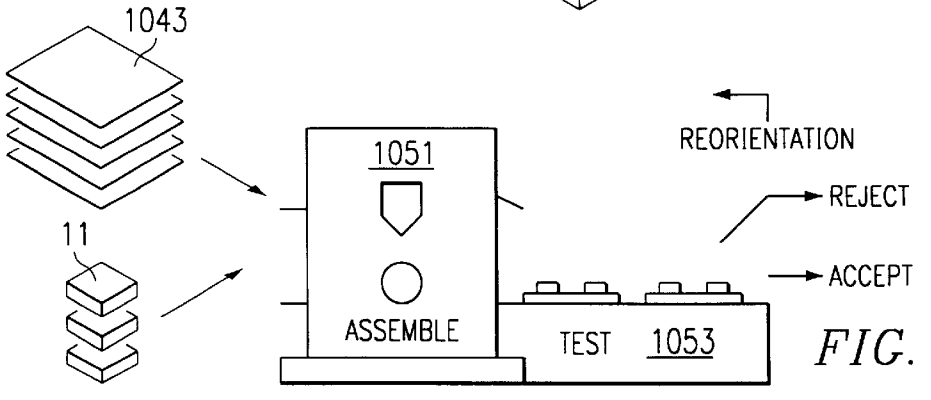


FIG. 38

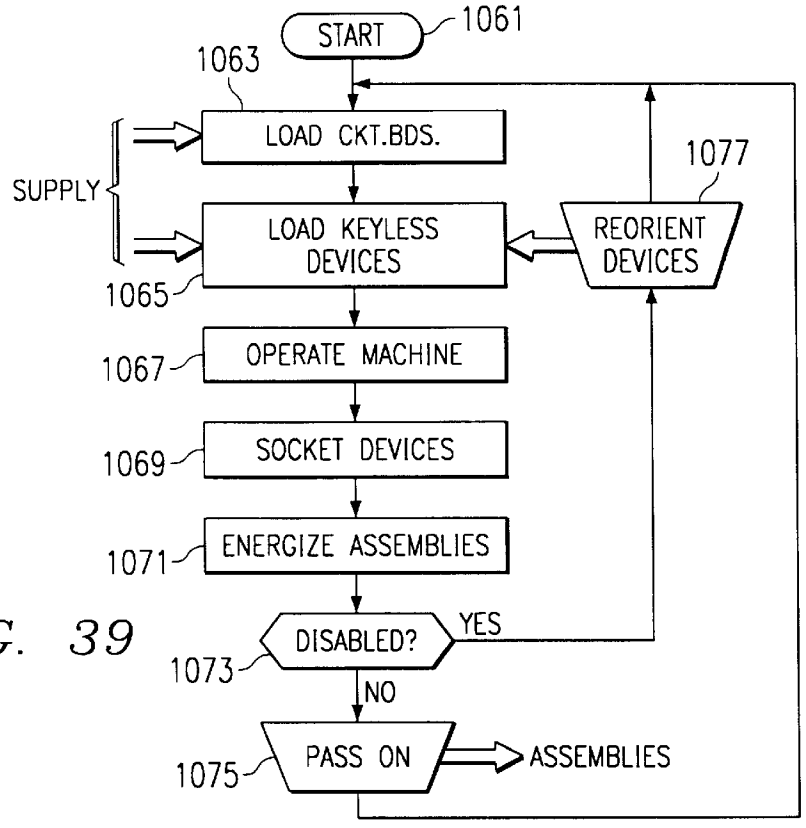


FIG. 39

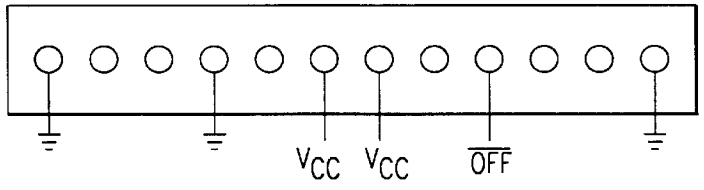


FIG. 40

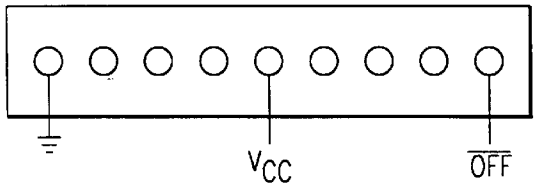


FIG. 41

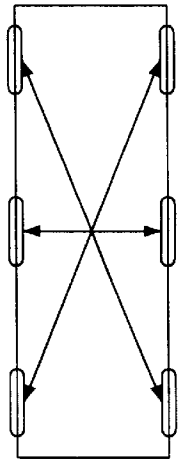


FIG. 42

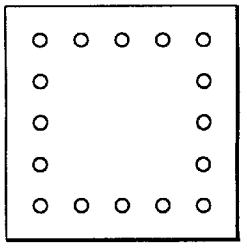


FIG. 43

DIGITAL SIGNAL PROCESSOR WITH WAIT STATE REGISTER

This application is a divisional of application Ser. No. 09/360,488, filed Jul. 23, 1999, now pending; which is a divisional of application Ser. No. 08/906,863, filed Aug. 6, 1997, now U.S. Pat. No. 5,946,483; which is a divisional of application Ser. No. 08/293,259, filed Aug. 19, 1994, now U.S. Pat. No. 5,907,714; which is a continuation of application Ser. No. 07/967,942, filed Oct. 28, 1992, now abandoned; which is a continuation of application Ser. No. 07/347,967, filed May 4, 1989, now abandoned.

NOTICE

(C) Copyright 1989 Texas Instruments Incorporated. A portion of the disclosure of this patent document contains material which is subject to copyright protection. The copyright owner has no objection to the facsimile reproduction by anyone of the patent disclosure, as it appears in the Patent and Trademark Office/ patent file or records, but otherwise reserves all copyright rights whatsoever.

CROSS REFERENCE TO RELATED APPLICATIONS

This patent is related to co-assigned U.S. Pat. Nos. 5,586,275; 5,072,418; 5,142,677; 5155,812; 5,829,054; and 5,724,248, all filed contemporaneously herewith and incorporated herein by reference.

This invention relates to data processing devices, electronic processing and control systems and methods of their manufacture and operation.

BACKGROUND OF THE INVENTION

A microprocessor device is a central processing unit or CPU for a digital processor which is usually contained in a single semiconductor integrated circuit or "chip" fabricated by MOS/LSI technology, as shown in U.S. Pat. No. 3,757,306, issued to Gary W. Boone and assigned to Texas Instruments Incorporated. The Boone patent shows a single-chip 8-bit CPU including a parallel ALU, registers for data and addresses, an instruction register and a control decoder, all interconnected using the von Neumann architecture and employing a bidirectional parallel bus for data, address and instructions. U.S. Pat. No. 4,074,351, issued to Gary W. Boone and Michael J. Cochran, assigned to Texas Instruments Incorporated, shows a single-chip "microcomputer" type device which contains a 4-bit parallel ALU and its control circuitry, with on-chip ROM for program storage and on-chip RAM for data storage, constructed in the Harvard architecture. The term microprocessor usually refers to a device employing external memory for program and data storage, while the term microcomputer refers to a device with on-chip ROM and RAM for program and data storage. In describing the instant invention, the term "microcomputer" will be used to include both types of devices, and the term "microprocessor" will be primarily used to refer to microcomputers without on-chip ROM. Since the terms are often used interchangeably in the art, however, it should be understood that the use of one of the other of these terms in this description should not be considered as restrictive as to the features of this invention.

Modern microcomputers can be grouped into two general classes, namely general-purpose microprocessors and special-purpose microcomputers/microprocessors. General purpose microprocessors, such as the M68020 manufactured by Motorola, Inc. are designed to be programmable by the user to perform any of a wide range of tasks, and are therefore often used as the central processing unit in equipment such as personal computers. Such general-purpose microprocessors, while having good performance for a wide range of arithmetic and logical functions, are of course not specifically designed for or adapted to any particular one of such functions. In contrast, special-purpose microcomputers are designed to provide performance improvement for specific predetermined arithmetic and logical functions for which the user intends to use the microcomputer. By knowing the primary function of the microcomputer, the designer can structure the microcomputer in such a manner that the performance of the specific function by the special-purpose microcomputer greatly exceeds the performance of the same function by the general-purpose microprocessor regardless of the program created by the user.

One such function which can be performed by a special-purpose microcomputer at a greatly improved rate is digital signal processing, specifically the computations required for the implementation of digital filters and for performing Fast Fourier Transforms. Because such computations consist to a large degree of repetitive operations such as integer multiply, multiple-bit shift, and multiply-and-add, a special-purpose microcomputer can be constructed specifically adapted to these repetitive functions. Such a special-purpose microcomputer is described in U.S. Pat. No. 4,577,282, assigned to Texas Instruments Incorporated and incorporated herein by reference. The specific design of a microcomputer for these computations has resulted in sufficient performance improvement over general purpose microprocessors to allow the use of such special-purpose microcomputers in real-time applications, such as speech and image processing.

Digital signal processing applications, because of their computation intensive nature, also are rather intensive in memory access operations. Accordingly, the overall performance of the microcomputer in performing a digital signal processing function is not only determined by the number of specific computations performed per unit time, but also by the speed at which the microcomputer can retrieve data from, and store data to, system memory. Prior special-purpose microcomputers, such as the one described in said U.S. Pat. No. 4,577,282, have utilized modified versions of a Harvard architecture, so that the access to data memory may be made independent from, and simultaneous with, the access of program memory. Such architecture has, of course provided for additional performance improvement.

The increasing demands of technology and the marketplace make desirable even further structural and process improvements in processing devices, systems and methods of operation and manufacture.

Among the objects of the present invention are to provide improved data processing devices, systems and methods that avoid time-consuming processor operation disruptions due to unnecessary branching; to provide improved data processing devices, systems and methods that enhance operational flexibility, computational resolution, and increase system and processor throughput; to provide improved data processing devices, systems and methods for simplifying hardware at device and system levels; and to provide improved data processing devices, systems and methods for real-time operation.

SUMMARY OF THE INVENTION

In general, one form of the invention is a data processing device for use with peripheral devices having addresses and

differing communication response periods. The data processing device includes a digital processor adapted for selecting different ones of the peripheral devices by asserting addresses of each selected peripheral device. Addressable programmable registers hold wait state values representative of distinctive numbers of wait states corresponding to different address ranges. Circuitry is responsive to an asserted address to the peripheral devices asserted by the digital processor to generate the number of wait states represented by the value held in one of the addressable programmable registers corresponding to the one of the address ranges in which the asserted address occurs, thereby accommodating the differing communication response periods of the peripheral devices.

Other device, system, and method forms of the invention are also disclosed and claimed herein. Other objects of the invention are disclosed and still other objects will be apparent from the disclosure herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The preferred embodiments of the invention as well as other features and advantages thereof will be best understood by reference to the detailed description which follows, read in conjunction with the accompanying drawings, wherein:

FIGS. **1**A and **1**B are two halves of an electrical diagram in block form of an improved microcomputer device including a CPU or central processor unit formed on a single semiconductor chip

FIG. **2** is a block diagram of an improved industrial process and protective control system;

FIG. **3** is a partially pictorial, partially block electrical diagram of an improved automotive vehicle system;

FIG. **4** is an electrical block diagram of an improved motor control system;

FIG. **5** is an electrical block diagram of another improved motor control system;

FIG. **6** is an electrical block diagram of yet another improved motor control system;

FIG. **7** is an electrical block diagram of an improved robotic control system;

FIG. **8** is an electrical block diagram of an improved satellite telecommunications system;

FIG. **9** is an electrical block diagram of an improved echo cancelling system for the system of FIG. **8**;

FIG. **10** is an electrical block diagram of an improved modem transmitter;

FIG. **11** is an electrical block diagram equally representative of hardware blocks or process blocks for the improved modem transmitter of FIG. **10**;

FIG. **12** is an electrical block diagram equally representative of hardware blocks or process blocks for an improved modem receiver;

FIG. **13** is an electrical block diagram of an improved system including a host computer and a digital signal processor connected for PCM (pulse code modulation) communications;

FIG. **14** is an electrical block diagram of an improved video imaging system with multidimensional array processing;

FIG. **15** is an electrical block diagram equally representative of hardware blocks or process blocks for improved graphics, image and video processing;

FIG. **16** is an electrical block diagram of a system for improved graphics, image and video processing;

FIG. **17** is an electrical block diagram of an improved automatic speech recognition system;

FIG. **18** is an electrical block diagram of an improved vocoder-modem system with encryption;

FIG. **19** is a series of seven representations of an electronic register holding bits of information and illustrating bit manipulation operations of a parallel logic unit improvement of FIG. **1**B;

FIG. **20** is an electrical block diagram of an improved system for high-sample rate digital signal processing;

FIG. **21** is an electrical block diagram of architecture for an improved data processing device including the CPU of FIGS. **1**A and **1**B;

FIG. **22** a schematic diagram of a circuit for zero-overhead interrupt context switching;

FIG. **23** is a schematic diagram of an alternative circuit for zero-overhead interrupt context switching;

FIG. **24** is a schematic diagram of another alternative circuit for zero-overhead interrupt context switching;

FIG. **25** is a flow diagram of a method of operating the circuit of FIG. **24**;

FIG. **26** is a block diagram of an improved system including memory and I/O peripheral devices interconnected without glue logic to a data processing device of FIGS. **1**A and **1**B having software wait states on address boundaries;

FIG. **27** is a partially block, partially schematic diagram of a circuit for providing software wait states on address boundaries;

FIG. **28** is a process flow diagram illustrating instructions for automatically computing a maximum or a minimum in the data processing device of FIGS. **1**A and **1**B;

FIG. **29** is a partially graphical, partially tabular diagram of instructions versus instruction cycles for illustrating a pipeline organization of the data processing device of FIGS. **1**A and **1**B;

FIG. **30** is a further diagram of a pipeline of FIG. **29** comparing advantageous operation of a conditional instruction to the operation of a conventional instruction;

FIG. **31** is an electrical block diagram of an improved video system with a digital signal processor performing multiple-precision arithmetic using conditional instructions having the advantageous operation illustrated in FIG. **30**;

FIG. **32** is a block diagram of status bits and mask bits of a conditional instruction such as a conditional branch instruction;

FIG. **33** is a block diagram of an instruction register and an instruction decoder lacking provision for status and mask bits:

FIG. **34** is a block diagram detailing part of the improved data processing device of FIG. **1**A having an instruction register and decoder with provision for conditional instructions with status and mask bits;

FIG. **35** is a partially schematic, partially block diagram of circuitry for implementing the status and mask bits of FIGS. **32** and **34**;

FIG. **36** is a pictorial of an improved pin-out or bond-out configuration for a chip carrier for the data processing device of FIGS. **1**A and **1**B illustrating improvements applicable to configurations for electronic parts generally;

FIG. **37** is a pictorial view of four orientations of the chip carrier of FIG. **36** on a printed circuit in manufacture;

FIG. **38** is a pictorial of an automatic chip socketing machine and test area for rejecting and accepting printed circuits of FIG. **37** in manufacture;

FIG. **39** is a processing method of manufacture utilizing the system of FIG. **38**;

FIG. **40** is a version of the improved pin-out configuration in a single in-line type of chip;

FIG. **41** is another version of the improved pin-out configuration;

FIG. **42** is a pictorial of a dual in-line construction wherein the improved pin-out configuration is applicable and showing translation arrows; and

FIG. **43** is a pictorial of some pins of a pin grid array construction wherein the improved pin-out configuration is applicable.

Corresponding numerals and other symbols refer to corresponding parts in the various figures of drawing except where the context indicates otherwise.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An architectural overview first describes a preferred embodiment digital signal processing device **11**.

The preferred embodiment digital signal processing device **11** of FIGS. **1**A and **1**B implements a Harvard-type architecture that maximizes processing power by maintaining two separate memory bus structures, program and data, for full-speed execution. Instructions are included to provide data transfers between the two spaces.

The device **11** has a program addressing circuit **13** and an electronic computation circuit **15** comprising a processor. Computation circuit **15** performs two's-complement arithmetic using a 32 bit ALU **21** and accumulator **23**. The ALU **21** is a general-purpose arithmetic logic unit that operates using 16-bit words taken from a data memory **25** of FIG. **1**B or derived from immediate instructions or using'the. **32**-bit result of a multiplier **27**. In addition to executing arithmetic instructions, the ALU **21** can perform Boolean operations. The accumulator **23** stores the output from the ALU **21** and provides a second input to the ALU **21** via a path **29**. The accumulator **23** is illustratively 32 bits in length and is divided into a high-order word (bits **31** through **16**) and a low-order word (bits **15** through **0**). Instructions are provided for storing the high and low order accumulator words in data memory **25**. For fast, temporary storage of the accumulator **23** there is a 32-bit accumulator buffer ACCB **31**.

In addition to the main ALU **21** there is a Peripheral Logic Unit (PLU) **41** in FIG. **1**B that provides logic operations on memory locations without affecting the contents of the accumulator **23**. The PLU **41** provides extensive bit manipulation ability for high-speed control purposes and simplifies bit setting, clearing, and testing associated with control and status register operations.

The multiplier **27** of FIG. **1**A performs a 16×16 bit two's complement multiplication with a 32-bit result in a single instruction cycle. The multiplier consists of three elements: a temporary TREGO register **49**, product register PREG **51** and multiplier array **53**. The 16-bit TREGO register **49** temporarily stores the multiplicand; the PREG register **51** stores the 32-bit product. Multiplier values either come from data memory **25**, from a program memory **61** when using the MAC/MACD instructions, or are derived immediately from the MPYK (multiply immediate) instruction word.

Program memory **61** is connected at addressing inputs to a program address bus **101**A. Memory **61** is connected at its read/write input/output to a program data bus **101**D. The fast on-chip multiplier **27** allows the device **11** to efficiently perform fundamental DSP operations such as convolution, correlation, and filtering.

A processor scaling shifter **65** has a **16**-bit input connected to a data bus **111**D via a multiplexer (MUX) **73**, and a **32**-bit output connected to the ALU **21** via a multiplexer **77**. The scaling shifter **65** produces a left-shift of 0 to 16 bits on the input data, as programmed by instruction or defined in a shift count register (TREG1) **81**. The LSBs (least significant bits) of the output are filled with zeros, and the MSBs (most significant bits) may be either filled with zeros or sign-extended, depending upon the state of the sign-extension mode bit SXM of the status register ST1 in a set of registers **85** of FIG. **1**B. Additional shift capabilities enable the processor **11** to perform numerical scaling, bit extraction, extended arithmetic, and overflow prevention.

Up to eight levels of a hardware stack **91** are provided for saving the contents of a program counter **93** during interrupts and subroutine calls. Program counter **93** is selectively loaded upon a context change via a MUX **95** from program address bus **101**A or program data bus **101**D. The PC **93** is written to address bus **101**A or pushed onto stack **91**. On interrupts, certain strategic registers (accumulator **23**, product register **51**, TREGO **49**, TREG1, TREG2, and in register **113**: ST**0**, ST1, PMST, ARCR, INDX and CMPR) are pushed onto a one deep stack and popped upon interrupt return: thus providing a zero-overhead, interrupt context switch. The interrupts operative to save the contents of these registers are maskable.

The functional block diagram shown in FIGS. **1**A and **1**B outlines the principal blocks and data paths within the processor. Further details of the functional blocks are provided hereinbelow. Refer to Table A-1, the internal hardware summary, for definitions of the symbols used in FIGS. **1**A and **1**B.

The processor architecture is built around two major buses (couples): the program bus **101**A and **101**D and the data bus **111**A and **111**D. The program bus carries the instruction code and immediate operands from program memory on program data bus **101**D. Addresses to program memory **61** are supplied on program address bus **101**A. The data bus includes data address bus **111**A and data bus **111**D. The latter bus **111**D interconnects various elements, such as the Central Arithmetic Logic Unit (CALU) **15** and an auxiliary register file **115** and registers **85**, to the data memory **25**. Together, the program and data buses **101** and **111** can carry data from on-chip data memory **25** and internal or external program memory **61** to the multiplier **27** in a single cycle for multiply/accumulate operations. Data memory **25** and registers **85** are addressed via data address bus **111**A. A core register address decoder **121** is connected to data address bus **111**A for addressing registers **85** and all other addressable CPU core registers.

The processor **13**, **15** has a high degree of parallelism; e.g., while the data is being operated upon by the CALU **15**, arithmetic operations are advantageously implemented in an Auxiliary Register Arithmetic Unit (ARAU) **123**. Such parallelism results in a powerful set of arithmetic logic, and bit manipulation operations that may all be performed in a single machine cycle.

The processor internal hardware contains hardware for single-cycle 16×16-bit multiplication, data shifting and address manipulation.

Table A-1 presents a summary of the internal hardware. This summary table, which includes the internal processing

elements, registers, and buses, is alphabetized within each functional grouping.

TABLE A-1

	Internal Hardware	
UNIT	SYMBOL	FUNCTION
Accumulator	ACC(32) ACCH(16) ACCL(16)	A 32-bit accumulator accessible in two halves: ACCH (accumulator high) and ACCL (accumulator low). Used to store the output of the ALU.
Accumulator Buffer	ACCB(32)	A register used to temporarily store the 32-bit contents of the accumulator. This register has a direct path back to the ALU and therefore can be arithmetically or logically operated with the ACC.
Arithmetic Logic Unit	ALU	A 32-bit two's complement arithmetic logic unit having two 32-bit input ports and one 32-bit output port feeding the accumulator.
Auxiliary Arithmetic Unit	ARAU	A 16-bit unsigned arithmetic unit used to calculate indirect addresses using the auxiliary, index, and compare registers as inputs.
Auxiliary Register Compare	ARCR	A 16-bit register used in use as a limit to compare indirect address against.
Auxiliary Register File	AUXREGS	A register file containing eight 16-bit auxiliary registers (AR0–AR7), used for indirect data address pointers, temporary storage, or integer arithmetic processing through the ARAU.
Auxiliary Register Pointer	ARP	A 3-bit register used as a pointer to the currently selected auxiliary register.
Block Repeat Counter Register	BRCR	A 16-bit memory-mapped counter register used as a limit to the number of times the block is to be repeated.
Block Repeat Counter Register	PAER	A 16-bit memory-mapped register containing the end address of the segment of code being repeated.
Block Repeat Address Start Register	PASR	A 16-bit memory-mapped register containing the start address of the segment of code being repeated.
Bus Interface Module	BIM	A buffered interface used to pass data between the data and program buses.
Central Arithmetic Logic Unit	CALU	The grouping of the ALU, multiplier, accumulator, and scaling shifters.
Circular Buffer Control Register	CBCR	An 8-bit register used to enable/disable the circular buffers and define which auxiliary registers are mapped to the circular buffers.
Circular Buffer End Address	CBER1	Two 16-bit registers indicating circular buffer end addresses. CBER1 and CBER2 are associated with circular buffers one and two respectively.
Circular Buffer Start Address	CBSR1 CBSR2	Two 16-bit registers indicating circular buffer start addresses. CBSR1/CBSR2 are associated with circular buffers one and two respectively.

TABLE A-1-continued

	Internal Hardware	
UNIT	SYMBOL	FUNCTION
Data Bus	DATA	A 16-bit bus used to route data.
Data Memory	DATA MEMORY	This block refers to data memory used with the core and defined in specific device descriptions. It refers to both on and off-chip memory blocks accessed in data memory space.
Data Memory Address Immediate Register	DMA	A 7-bit register containing the immediate relative address within a data page.
Data Memory Page Pointer	DP(9)	A 9-bit register containing the address of the current page. Data pages are 128 words each, resulting in 512 pages of addressable data memory space (some locations are reserved).
Direct Data Memory Address Bus	DATA ADDRESS	A 16-bit bus that carries the direct address for the data memory, which is the concatenation of the DP register and the seven LSBs of the instruction (DMA).
Dynamic Bit Manipulation Register	DBMR	A 16-bit memory-mapped register used as an input to PLU.
Dynamic Bit Pointer	TREG2	A 4-bit register that holds a dynamic bit pointer for the BITT jnstruction.
Dynamic Shift Count	TREG1	A 5-bit register that holds a dynamic prescaling shift count for data inputs to the ALU.
Global Memory Allocation Register	GREG(8)	An 8-bit memory-mapped register for allocating the size of the global memory space.
Interrupt Flag Register	IFR(16)	A 16-bit flag register used to latch the active-low interrupts. The IFR is a memory mapped register.
Interrupt Mask Register	IMR(16)	A 16-bit memory mapped register used to mask interrupts.
Multiplexer	MUX	A bus multiplexer used to select the source of operands for a bus or execution unit. The MUXs are connected via instructions.
Multiplier	MULTI-PLIER	A 16 × 16 bit parallel multiplier.
Peripheral Logic Unit	PLU	A 16-bit logic unit that executes logic operations from either long immediate operands or the contents of the DBMR directly upon data locations without interfering with the contents of the CALU registers.
Prescaler Count Register	COUNT	A 4-bit register that contains the count value for the prescaling operation. This register is loaded from either the instruction or the dynamic shift count when used in prescaling data. In conjunction with the BIT and BITT instructions, it is loaded from the dynamic bit pointer of the instruction.
Product Register	PREG(32)	A 32-bit product register used to hold the multiplier product. The high and low

TABLE A-1-continued

Internal Hardware

UNIT	SYMBOL	FUNCTION
		words of the PREG can also be accessed individually using the SPH/SPL (store P register high/low) instructions.
Product Register Buffer	BPR(32)	A 32-bit register used for temporary storage of the product register. This register can also be a direct input to the ALU.
Program Bus	PROG DATA	A 16-bit bus used to route instructions (and data for the MAC and MACD instructions).
Program Counter	PC(16)	A 16-bit program counter used to address program memory sequentially. The PC always contains the address of the next instruction to be executed. The PC contents are updated following each instruction decode operation.
Program Memory	PROGRAM MEMORY	This block refers to program memory used with the core and defined in specific device descriptions. It refers to both on and off-chip memory blocks accessed in program memory space.
Program Memory Address Bus	PROG ADDRESS	A 16-bit bus that carries the program memory address.
Prescaling Shifter	PRESCALER	A 0 to 16-bit left barrel shifter used to prescale data coming into the ALU. Also used to align data for multi-precision operations. This shifter is also used as a 0–16 bit right barrel shifter of the ACC.
Postscaling Shifter	POST-SCALER	A 0–7 bit left barrel shifter used to post scale data coming out of the CALU.
Product Shifter	P-SCALER	A 0, 1, 4-bit left shifter used to remove extra sign bits (gained in the multiply operation) when using fixed point arithmetic. A 6-bit right shifter used to scale the products down to avoid overflow in the accumulation process.
Repeat Counter	RPTC(16)	An 8-bit counter to control the repeated execution of a single instruction.
Stack	STACK	A 8 × 16 hardware stack used to store the PC during interrupts and calls. The ACCL and data memory values may also be pushed onto the popped from the stack.
Status Registers	ST0,ST1, PMST, CBCR	Three 16-bit status registers that contain status and control bits.
Temporary Multiplicand	TREG0	A 16-bit register that temporarily holds an operand for the multiplier.
Block Move Address Register	BMAR	A 16-bit register that holds an address value for use with block moves or multiply accumulates.

There are **28** core processor registers mapped into the data memory space by decoder **121**. These are listed in Table A-2. There are an additional 64 data memory space registers reserved in page zero of data space. These data memory locations are reserved for peripheral control registers.

TABLE A-2

Memory Mapped Registers

	ADDRESS		
NAME	DEC	HEX	DESCRIPTION
	0–3	0–3	RESERVED
IMR	4	4	INTERRUPT MASK REGISTER
GREG	5	5	GLOBAL MEMORY ALLOCATION REGISTER
IFR	6	6	INTERRUPT FLAG REGISTER
PMST	7	7	PROCESSOR MODE STATUS REGISTER
RPTC	8	8	REPEAT COUNTER REGISTER
BRCR	9	9	BLOCK REPEAT COUNTER RGISTER
PASR	10	A	BLOCK REPEAT PROGRAM ADDRESS START REGISTER
PAER	11	B	BLOCK REPEAT PROGRAM ADDRESS END REGISTER
TREG0	12	C	TEMPORARY REGISTER USED FOR MULTIPLICAND
TREG1	13	D	TEMPORARY REGISTER USED FOR DYNAMIC SHIFT COUNT
TREG2	14	E	TEMPORARY REGISTER USED AS BIT POINTER IN DYNAMIC BIT TEST
DBMR	15	F	DYNAMIC BIT MANIPULATION REGISTER
AR0	16	10	AUXILIARY REGISTER ZERO
AR1	17	11	AUXILIARY REGISTER ONE
AR2	18	12	AUXILIARY REGISTER TWO
AR3	19	13	AUXILIARY REGISTER THREE
AR4	20	14	AUXILIARY REGISTER FOUR
AR5	21	15	AUXILIARY REGISTER FIVE
AR6	22	16	AUXILIARY REGISTER SIX
AR7	23	17	AUXILIARY REGISTER SEVEN
INDX	24	18	INDEX REGISTER
ARCR	25	19	AUXILIARY REGISTER COMPARE REGISTER
CBSR1	26	1A	CIRCULAR BUFFER 1 START ADDRESS REGISTER
CBER1	27	1B	CIRCULAR BUFFER 1 END ADDRESS REGISTER
CBSR2	28	1C	CIRCULAR BUFFER 2 START ADDRESS REGISTER
CBER2	29	1D	CIRCULAR BUFFER 2 END ADDRESS REGISTER
CBCR	30	1E	CIRCULAR BUFFER CONTROL REGISTER
BMAR	31	1F	BLOCK MOVE ADDRESS REGISTER

The processor **13, 15** addresses a total of 64K words of data memory **25**. The data memory **25** is mapped into the 96K data memory space and the on-chip program memory is mapped into a 64K program memory space.

The 16-bit data address bus **111**A addresses data memory **25** in one of the following two ways:

1) By a direct address bus (DAB) using the direct addressing mode (e.g. ADD 010h), or

2) By an auxiliary register file bus (AFB) using the indirect addressing mode (e.g. ADD*)

3) Operands are also addressed by the contents of the program counter in an immediate addressing mode.

In the direct addressing mode, a 9-bit data memory page pointer (DP) 125 points to one of 512 (128-word) pages. A MUX **126** selects on command either bus **101**D or **111**D for DP pointer register portion **125**. The data memory address (dma) specified from program data bus **101** by seven LSBs **127** of the instruction, points to the desired word within the page. The address on the DAB is formed by concatenating the 9-bit DP with the 7-bit dma. A MUX **129** selectively supplies on command either the ARAU **123** output or the concatenated (DP, dma) output to data address bus **111**A.

In the indirect addressing mode, the currently selected 16-bit auxiliary register AR(ARP) in registers **115** addresses the data memory through the AFB. While the selected

auxiliary register provides the data memory address and the data is being manipulated by the CALU **15**, the contents of the auxiliary register may be manipulated through the ARAU **123**.

The data memory address map can be extended beyond the 64K-word address reach of the 16-bit address bus by paging in an additional 32K words via the global memory interface. By loading the GREG register with the appropriate value, additional memory can be overlaid over the local data memory starting at the highest address and moving down. This additional memory is differentiated from the local memory by the BR-pin being active low.

When an immediate operand is used, it is either contained within the instruction word itself or, in the case of 16-bit immediate operands, the word following the instruction word.

Eight auxiliary registers (AR**0**–AR**7**) in the auxiliary registers **115** are used for indirect addressing of the data memory **25** or for temporary data storage. Indirect auxiliary register addressing allows placement of the data memory address of an instruction operand into one of the auxiliary registers. These registers are pointed to by a three-bit auxiliary register pointer (ARP) **141** that is loaded with a value from 0 through 7, designating AR**0** through AR**7**, respectively. A MUX **144** has inputs connected to data bus **111**D and program data bus **11**D. MUX **144** is operated by instruction to obtain a value for ARP **141** from one of the two buses **111**D and **101**D. The auxiliary registers **115** and the ARP **141** may be loaded either from data memory **25**, the accumulator **23**, the product register **51**, or by an immediate operand defined in the instruction. The contents of these registers may also be stored in data memory **25** or used as inputs to the main CPU.

The auxiliary register file (AR**0**–AR**7**) **115** is connected to the Auxiliary Register Arithmetic Unit (ARAU) **123** shown in FIG. **1**B. The ARAU **123** may autoindex the current auxiliary register in registers **115** while the data memory location is being addressed. Indexing by either +/−1 or by the contents of an index register **143** or AR**0** may be performed. As a result, accessing tables of information by rows or columns does not require the Central Arithmetic Logic Unit (CALU) **15** for address manipulation, thus freeing it for other operations.

The index register **143** or the eight LSBs of an instruction register IR are selectively connected to one of the inputs of the ARAU **123** via a MUX **145**. The other input of ARAU **123** is fed by a MUX **147** from the current auxiliary register AR (being pointed to by ARP). AR(ARP) refers to the contents of the current AR **115** pointed to by ARP. The ARAU **123** performs the following functions.

("--" means "loaded into")

AR(ARP) + INDX -- AR(ARP)	Index the current AR by adding a 16-bit integer contained in INDX.
AR(ARP) − INDX -- AR (ARP)	Index the current AR by subtracting a 16-bit integer contained in INDX.
AR(ARP) + 1-- AR(ARP)	Increment the current AR by one.
AR(ARP) −1 -- AR(ARP)	Decrement the current AR by one.
AR(ARP) -- AR(ARP)	Do not modify the current AR.
AR(ARP) + IR(7-0) -- AR(ARP)	ADD an 8-bit immediate value to current AR.
AR(ARP) − IR(7-0) -- AR(ARP)	Subtract an 8-bit immediate value from current AR.
AR(ARP) + rc(INDX) -- AR(ARP)	Bit-reversed indexing, add INDX with reverse carry (rc) propagation.
AR(ARP) − rc(INDX) -- AR(ARP)	Bit-reversed indexing, subtract INDX with reverse-carry (rc) propagation.

if (AR(ARP) = ARCR) then TC = 1
if (AR(ARP)gt ARCR) then TC = 1
if (AR(ARP)lt ARCR) then TC = 1
if (AR(ARP)neq ARCR) then TC = 1
	Compare current AR with ARCR and if comparison is true then set TC bit of the status register (ST1) to one. If false then clear TC.

if(AR(ARP) = CBER)then AR(ARP) = CBSR	If at end of circular buffer reload start address

The index register (INDX) can be added to or subtracted from AR(ARP) on any AR update cycle. This 16-bit register is one of the memory-mapped registers. This 16-bit register is used to step the address in steps larger than one and is used in operatios such as addressing down a column of a matrix. The auxiliary register compare register (ARCR) is used as a limit to blocks of data and in conjunction with the C14PR instruction supports logical comparisons between AR(ARP) and ARCR.

Because the auxiliary registers **115** are memory-mapped, they can be acted upon directly by the CALU **15** to provide for more advanced indirect addressing techniques. For example, the multiplier **27** can be used to calculate the addresses of three dimensional matrices. There is a two machine cycle delay after a CALU load of the auxiliary register until auxiliary registers can be used for address generation.

Although the ARAU **123** is useful for address manipulation in parallel with other operations, it suitably also serves as an additional general-purpose arithmetic unit since the auxiliary register file can directly communicate with data memory. The ARAU implements 16-bit unsigned arithmetic, whereas the CALU implements 32-bit two's complement arithmetic. BANZ and BANZD instructions permit the auxiliary registers to also be used as loop counters.

A 3-bit auxiliary register pointer buffer (ARB) **148** provides storage for the ARP on subroutine calls.

The processor supports two circular buffers operating at a given time. These two circular buffers are controlled via the Circular Buffer Control Register (CBCR) in registers **85**. The CBCR is defined as follows:

BIT	NAME	FUNCTION
0–2	CAR1	Identifies which auxiliary register is mapped to circular buffer 1.
3	CENB1	Circular buffer 1 enable = 1/disable = 0. Set 0 upon reset.
4–6	CAR2	Identifies which auxiliary register is mapped to circular buffer 2.
7	CENB2	Circular buffer 2 enable = 1/disable = 0. Set 0 upon reset.

Upon reset (RS-rising edge) both circular buffers are disabled. To define each circular buffer first load the CBSR1

and CBSR2 with the respective start addresses of the buffers and CBER1 and CBER2 with the end addresses. Then load respective auxiliary registers AR(i1) and AR(i2) in registers **115** to be used with each circular buffer with an address between the start and end. Finally load CBCR with the appropriate auxiliary register number i1 or i2 for ARP and set the enable bit. As the address is stepping through the circular buffer, the update is compared by ARAU **123** against the value contained in CBER **155**. When equal, the value contained in CBSR **157** is automatically loaded into the AR auxiliary register AR(i1) or AR(i2) for the respective circular buffer.

Circular buffers can be used with either incremented or decremented type updates. If using increment, then the value in CBER is greater than the value in CBSR. When using decrement, the greater value is in the CBSR. The other indirect addressing modes also can be used wherein the ARAU **123** tests for equality of the AR and CBER values. The ARAU does not detect an AR update that steps over the value contained in CBER **155**.

As shown in FIG. 1B, the data bus **111**D is connected to supply data to MUXes **144** and **126**, auxiliary registers **115** and registers CBER **155**, INDX **143**, CBSR **157** and an address register compare register ARCR **159**. MUX **145** has inputs connected to registers CBER, INDX and ARCR and instruction register IR for supplying ARAU **123**.

The preferred embodiment provides instructions for data and program block moves and for data move functions that efficiently utilize the memory spaces of the device. A BLDD instruction moves a block within data memory, and a BLPD instruction moves a block from program memory to data memory. One of the addresses of these instructions comes from a data address generator, and the other comes from either a long immediate constant or a Block Move Address Register (BMAR) **160**. When used with the repeat instructions (RPT/RPTK/RPTR/RPTZ), the BLDD/BLPD instructions efficiently perform block moves from on-chip or off-chip memory.

A data move instruction DMOV allows a word to be copied from the currently addressed data memory location in on-chip RAM to the next higher location while the data from the addressed location is being operated upon in the same cycle (e.g. by the CALU). An ARAU operation may also be performed in the same cycle when using the indirect addressing mode. The DMOV function is useful for implementing algorithms that use the Z^{-1} delay operation, such as convolutions and digital filtering where data is being passed through a time window. The data move function can be used anywhere within predetermined blocks. The MACD (multiply and accumulate with data move) and the LTD (load TREG0 with data move and accumulate product) instructions use the data move function.

TBLR/TBLW (table read/write) instructions allow words to be transferred between program and data spaces. TBLR is used to read words from program memory into data memory. TBLW is used to write words from data memory to program memory.

As described above, the Central Arithmetic Logic Unit (CALU) **15** contains a 16-bit prescaler scaling shifter **65**, a 16×16-bit parallel multiplier **27**, a 32-bit Arithmetic Logic Unit (ALU) **21**, a 32-bit accumulator (ACC) **23**, and additional shifters **169** and **181** at the outputs of both the accumulator **23** and the multiplier **27**. This section describes the CALU components and their functions.

The following steps occur in the implementation of a typical ALU instruction:

1) Data is fetched from the RAM **25** on the data bus.
2) Data is passed through the scaling shifter **65** and the ALU **21** where the arithmetic is performed, and
3) The result is moved into the accumulator **23**.

One input to the ALU **21** is provided from the accumulator **23**, and the other input is selected from the Product Register (PREG) **51** of the multiplier **27**, a Product Register Buffer (BPR) **185**, the Accumulator Buffer (ACCB) **31** or from the scaling shifters **65** and **181** that are loaded from data memory **25** or the accumulator **23**.

Scaling shifter **65** advantageously has a 16-bit input connected to the data bus **111**D via MUX **73** and a 32-bit output connected to the ALU **21** via MUX **77**. The scaling shifter prescaler **65** produces a left shift of 0 to 16 bits on the input data, as programmed by loading a COUNT register **199**. The shift count is specified by a constant embedded in the instruction word, or by a value in register TREG1. The LSBs of the output of prescaler **65** are filled with zeros, and the MSBs may be either filled with zeros or sign-extended, depending upon the status programmed into the SXM (sign-extension mode) bit of status register ST1.

The same shifter **65** has another input path from the accumulator **23** via MUX **73**. When using this path the shifter **65** acts as a 0 to 16 bit right shifter. This allows the contents of the ACC to be shifted 0 to 16 bits right in a single cycle. The bits shifted out are lost and the bits shifted in are either zeros or copies of the original sign bit depending on the value of the SXM status bit.

The various shifters **65**, **169** and **181** allow numerical scaling, bit extraction, extended-precision arithmetic, and overflow prevention.

The 32-bit ALU **21** and accumulator **23** implement a wide range of arithmetic and logical functions, the majority of which execute in a single clock cycle in the preferred embodiment. once an operation is performed in the ALU **21**, the result is transferred to the accumulator **23** where additional operations such as shifting may occur. Data that is input to the ALU may be scaled by the scaling shifter **181**.

The ALU **21** is a general-purpose arithmetic unit that operates on 16-bit words taken from data RAM or derived from immediate instructions. in addition to the usual arithmetic instructions, the ALU can even perform Boolean operations. As mentioned hereinabove, one input to the ALU is provided from the accumulator **23**, and the other input is selectively fed by MUX **77**. MUX **77** selects the Accumulator Buffer (ACCB) **31** or secondly the output of the scaling shifter **65** (that has been read from data RAX or from the ACC), or thirdly, the output of product scaler **169**. Product scaler **169** is fed by a MUX **191**. MUX **191** selects either the Product Register PREG **51** or the Product Register Buffer **185** for scaler **169**.

The 32-bit accumulator **23** is split into two 16-bit segments for storage via data bus **111**D to data memory **25**. Shifter **181** at the output of the accumulator provides a left shift of 0 to 7 places. This shift is performed while the data is being transferred to the data bus **111**D for storage. The contents of the accumulator **23** remain unchanged. When the post-scaling shifter **181** is used on the high word of the accumulator **23** (bits **16–31**), the MSBs are lost and the LSBs are filled with bits shifted in from the low word (bits **0–15**). When the post-scaling shifter **181** is used on the low word, the LSB's are zero filled.

Floating-point operations are provided for applications requiring a large dynamic range. The NORM (normalization) instruction is used to normalize fixed point numbers contained in the accumulator **21** by performing left shifts. The four bits of temporary register TREG1 **81** define a variable shift through the scaling shifter **65** for the LACT/

ADDT/SUBT (load/add-to/subtract from accumulator with shift specified by TREG1) instructions. These instructions are useful in floating-point arithmetic where a number needs to be denormalized, i.e., floating-point to fixed-point conversion. They are also useful in applications such as execution of an Automatic Gain Control (AGC) going into a filter. The BITT (bit test) instruction provides testing of a single bit of a word in data memory based on the value contained in the four LSBS of a temporary register TREG2 **195**.

Registers TREG1 and TREG2 are fed by data bus **111**D. A MUX **197** selects values from TREG1, TREG2 or from program data bus **101**D and feeds one of them to a COUNT register **199**. COUNT register **199** is connected to scaling shifter **65** to determine the amount of shift.

The single-cycle Q-to-16-bit right shift of the accumulator **23** allows efficient alignment of the accumulator for multiprecision arithmetic. This coupled with the 32-bit temporary buffers ACCB on the accumulator and BPR on the product register enhance the effectiveness of the CALU in multiprecision arithmetic. The accumulator buffer register (ACCR) provides a temporary storage place for a fast save of the accumulator. ACCB can be also used as an input to the ALU. ACC and ACCB can be stored into each other. The contents of the ACCB can be compared by the ALU against the ACC with the larger/smaller value stored in the ACCB (or in both ACC and ACCB)for use in pattern recognition algorithms. For instance, the maximum or minimum value in a string of numbers is advantageously found by comparing the contents of the ACCB and ACC, and if the condition is met then putting the minimum or maximum into one or both registers. The product register buffer (BPR) provides a temporary storage place for a fast save of the product register. The value stored in the BPR can also be added to/subtracted from the accumulator with the shift specified for the provided shifter **169**.

An accumulator overflow saturation mode may be programmed through the SOVM and ROVM (set/reset overflow mode) instructions. When the accumulator **73** is in the overflow saturation mode and an overflow occurs, the overflow flag (OVM bit of register ST**0**) is set and the accumulator is loaded with either the most positive or the most negative number depending upon the direction of the overflow. The value of the accumulator upon saturation is 07FFFFFFh (positive) or 0800000000h (negative). Ir the OVM (overflow mode) status register bit is reset and an overflow occurs, the overflowed results are loaded into the accumulator with modification. (Note that logical operations do not result in overflow.)

A variety of branch instructions depend on the status conditions of the ALU and accumulator. These status conditions include the V (branch on overflow) and Z (branch on accumulator equal to zero), L (branch on less than zero) and C (branch on carry). In addition, the BACC (branch to address in accumulator) instruction provides the ability to branch to an address specified by the accumulator (computed goto). Bit test instructions (BIT and BITT), which do not affect the accumulator, allow the testing of a specified bit of a word in data memory.

The accumulator has an associated carry bit C in register ST1 that is set or reset depending on various operations within the device. The carry bit allows more efficient computation of extended-precision products and additions or subtractions. It is also useful in overflow management. The carry bit is affected by most arithmetic instructions as well as the single bit shift and rotate instructions. It is not affected by loading the accumulator, logical operations, or other such nonarithmetic or control instructions. Examples of carry bit operation are shown in Table A-3.

TABLE A-3

Examples of Carry Bit Operation

C	MSB	LSB	C	MSB	LSB
X	FFFF	FFFF ACC	X	0000	0000 ACC
	+	1		−	1
1	0000	0000	0	FFFF	FFFF
X	7FFF	FFFF ACC	X	8000	0001 ACC
	+	1 (OVM = 0)		−	2 (OVM = 0)
0	8000	0000	1	7FFFF	FFFF
1	0000	0000 ACC	X	FFFF	FFFF ACC
	+	0 (ADDC)		−	1 (SUBB)
0	0000	0001	1	FFFF	FFFE

The value added to or subtracted from the accumulator, shown in the example of Table A-3 may come from either the input scaling shifter, ACCR, PREG or BPR. The carry bit is set if the result of an addition or accumulation process generates a carry, or reset to zero if the result of a subtraction generates a borrow. Otherwise, it is reset after an addition or set after a subtraction. a

The ADDC (add to accumulator with carry) and SUBB (subtract from accumulator with borrow) instructions provided use the previous value of carry in their addition/subtraction operation. The ADCR (add ACCB to accumulator with carry) and the SBBR (subtract ACCR from accumulator with borrow) also use the previous value of carry C.

An exception to operation of the carry bit is the use of ADD with a shift count of 16 (add to high accumulator) and SUB with a shift count of 16 (subtract from high accumulator) instructions. The case of the ADD instruction sets the carry bit if a carry is generated, and this case of the SUB instruction resets the carry bit if a borrow is generated. Otherwise, neither instruction affects it.

Two branch instructions, BC and BNC, are provided for branching on the status of the carry bit. The SETC, CLRC and LST1 instructions can also be used to load the carry bit. The carry bit is set to one on a hardware reset.

The SFL and SFR (in-place one-bit shift to the left/right) instructions and the ROL and ROR (rotate to the left/right) instructions implement shifting or rotating of the contents of the accumulator through the carry bit. The SXM bit affects the definition of the SFR (shift accumulator right) instruction. When SXM-**1**, SFR performs an arithmetic right shift, maintaining the sign of the accumulator data. When SXK-**0**, SFR performs a logical shift, shifting out the LSBs and shifting in a zero for the MSB. The SFL (shift accumulator left instruction is not affected by the SXM bit and behaves the same in both cases, shifting out the KSB and shifting in a zero. Repeat (RPT, RPTK, RPTR or RPTZ) instructions may be used with the shift and rotate instructions for multiple-bit shifts.

The 65-bit combination of the accumulator, ACCB, and carry bit can be shifted or rotated as described above using the SFLR, SFRR, RORR and ROLR instructions.

The accumulator can also be right-shifted 0–31 bits in two instruction cycles or 0–16 bits in one cycle. The BSAR instruction shifts the accumulator 1–16 bits based upon the four bit value in the instruction word. The SATL instruction shifts the accumulator to the right based upon the 4-LSBs of

TREG1. The SATE instruction shifts the accumulator 16-bits if bit **5** of TREG1 is a one.

The 16×16-bit hardware multiplier **27** computes a signed or unsigned 32-bit product in a single machine cycle. All multiply instructions, except MPYU (multiply unsigned) instruction perform a signed multiply operation in the multiplier. That is, two numbers being multiplied are treated as twoas-complement numbers, and the result is a 32-bit twoas-complement number. The following three registers are associated with the multiplier.

The 16-bit temporary register (TREGO) **49** connected to the data bus that holds one of the operands for the multiplier.

The 32-bit product register (PREG) **51** that holds the product, and The 32-bit product buffer (BPR) **185** that is used to temporarily store the PREG **51**.

The output of the product register **51** and product buffer **185** can be left-shifted according to four product shift modes (PM), which are useful for implementing multiply/accumulate operations, fractional arithmetic or justifying fractional products. The PM field of status register ST1 specifies the PM shift mode. The product is shifted one bit to compensate for the extra sign bit gained in multiplying two 16-bit two's-complement numbers (MPY). A four bit shift is used in conjunction with an XPYK instruction to eliminate the four extra sign bits gained in multiplying a 16-bit number times a 13-bit number. The output of PREG and BPR can instead be right-shifted 6 bits to enable the execution of up to 128 consecutive multiply/accumulates without the possibility of overflow. When right shift is specified, the product is sign-extended, regardless of the value of SXM.

An LT (load TREG**0**) instruction normally loads the TREG**0** **49** to provide one operand (from the data bus), and the MPY (multiply) instruction provides the second operand (also from the data bus). A multiplication can also be performed with an immediate operand using the MPYK instruction. In either case, a product can be obtained every two cycles.

Four multiply/accumulate instructions (MAC and MACD, MADS and MADD) fully utilize the computational bandwidth of the multiplier **27**, allowing both operands to be processed simultaneously. A MUX **211** selects either data bus **111**D or program data bus **101**D to feed a second input of multiplier array **53**. The data for these operations can be thus transferred to the multiplier each cycle via the program and data buses. This provides for single-cycle multiply/accumulates when used with repeat (RPT, RPTK, RTPR, RPTZ) instructions. The SQRA (square/add) and SQRS (square/subtract) instructions pass the same value to both inputs of the multiplier for squaring a data memory value.

The MPYU instruction performs an unsigned multiplication, which greatly facilitates extended precision arithmetic operations. The unsigned contents of TREG**0** are multiplied by the unsigned contents of the addressed data memory location, with the result placed in PREG. This allows operands of greater than 16 bits to be broken down into 16-bit words and processed separately to generate products of greater than 32-bits.

After the multiplication of two 16-bit numbers, the 32-bit product is loaded into the 32-bit Product Register (PREG) **51**. The product from the PREG may be transferred to the ALU, to the Product Buffer (BPR) or to data memory **25** via the SPH (Store Product High) and SPL (Store Product Low). Temporarily storing the product in BPR for example is vital to efficient execution of algorithms such as the transposed form of the IIR (infinite impulse response) digital filter. Use of BPR avoids unnecessary subsequent recomputation of the product of the same two operands.

As discussed above, four product shift modes (PM) are available at the PREG and BPR outputs, which are useful when performing multiply/accumulate operations, fractional arithmetic, or justifying fractional products. The PM field of status register ST**1** specifies the PM shift mode, as shown below:

PM	RESULTING SHIFT
00	NO SHIFT
01	LEFT SHIFT OF 1 BIT
10	LEFT SHIFT OF 4 BITS
11	RIGHT SHIFT OF 6 BITS

Left shifts specified by the PM value are useful for implementing fractional arithmetic or justifying fractional products. for example, the product of either two normalized, 16-bit, two's-complement numbers or two Q15 numbers contains two sign bits, one of which is redundant. Q15 format, one of the various types of Q format, is a number representation commonly used when performing operations on non-integer numbers. The single-bit-left-shift eliminates this extra sign bit from the product when it is transferred to the accumulator. This results in the accumulator contents being formatted in the same manner as the multiplicands. Similarly, the product of either a normalized, 16-bit, two's-complement or Q15 number and a 13-bit, two's-complement constant (MPYK) contains five sign bits, four of which are redundant. Here the four-bit shift property aligns the result as it is transferred to the accumulator.

Use of the right-shift PM value allows the execution of up to 128 consecutive multiply/accumulate operations without the threat of an arithmetic overflow, thereby avoiding the overhead of overflow management. The shifter can be disabled to cause no shift in the product when working with integer or 32-bit precision operations. Note that the PM right shift is always sign-extended regardless of the state of SXH.

System control is provided by the program counter **93**, hardware stack **91**, PC-related hardware, the external reset signal RS-, interrupts to an interrupt control **231**, the status registers, and the repeat counters. The following sections describe the function of each of these components in system control and pipeline operation.

The processor has 16-bit Program Counter (PC) **93**, and an eight deep hardware stack **91** provides PC storage. The program counter **93** addresses internal and external program memory **61** in fetching instructions. The stack **91** is used during interrupts and subroutines.

The program counter **93** addresses program memory **61**, either on-chip or off-chip, via the Program Address Bus (PAB) **101**A. Through the PAB, an instruction is addressed in program memory **61** and loaded via program data bus **101**D into the Instruction Register (IR) for a decoder PLA **221**. When the IR is loaded, the PC **93** is ready to start the next instruction fetch cycle. Decoder PLA (programmable logic array) **221** has numerous outputs for controlling the MUXes and all processor elements in order to execute the instructions in the processor instruction set. For example, decoder PLA **221** feeds command signals to a pipeline controller **225** which also has various outputs for implementing the pipelined processing operations so that the processor elements are coordinated in time. The outputs of pipeline controller **225** also include CALL, RET (RETURN), IAQ (interrupt acquisition) and TACK (interrupt acknowledge).

Data memory **25** is addressed by the program counter **93** during a BLKD instruction, which moves data blocks from

one section of data memory to another. The contents of the accumulator **23** may be loaded into the PC **93** in order to implement "computed GOTO" operations. This can be accomplished using the BACC (branch to address in accumulator) or CALA (call subroutine indirect) instructions.

To start a new fetch cycle, the PC **933** is loaded either with PC+1 or with a branch address (for instructions such as branches, calls, or interrupts). In the case of special conditional branches where the branch is not taken, the PC is incremented once more beyond the location of the branch immediate. In addition to the conditional branches, the processor has a full complement of conditional calls and returns.

The processor **13**, **15** operates with a four deep pipeline. This means any discontinuity in the PC **93** (i.e., branch call or interrupt) forces the device to flush two instructions from the pipeline. To avoid these extra cycles, the processor has a full set of delayed branches, calls and returns. In the delayed operation of the branches, calls or returns, the two instructions following the delayed instruction are executed while the instructions at the branch address are being fetched, therefore, not flushing the pipeline and giving an effective two cycle branch. If the instruction following the delayed branch is a two word instruction, then only it will be executed.

A further feature allows the execution of the next single instruction N+1 times. N is defined by loading a 16-bit RPTC (repeat counter) in registers **85**. When this repeat feature is used, the instruction is executed, and the RPTC is decremented until the RPTC goes to zero. This feature is useful with many instructions, such as NORM (normalize contents of accumulator), MACD (multiply and accumulate with data move), and SUBC (conditional subtract). When repeating instructions, the program address and data buses are freed to fetch a second operand in parallel with the data address and data buses. This allows instructions such as MACD and BLKP to effectively execute in a single cycle when repeated.

The PC stack **91** is 16-bits wide and eight levels deep. The PC stack **91** is accessible through the use of the push and pop instructions. Whenever the contents of the PC **93** are pushed onto the top of the stack **91**, the previous contents of each level are pushed down, and the bottom (eighth) location of the stack is lost. Therefore, data is lost if more than eight successive pushes occur before a pop. The reverse happens on pop operations. Any pop after seven sequential pops yields the value of the bottom stack level. All of the stack levels then contain the same value. The two instructions, PSHD and POPD, push a data memory value onto the stack or pop a value from the stack to or from data memory via data bus **111**D. These instructions allow a stack to be built in data memory for the nesting of subroutines/interrupts beyond eight levels.

Instruction pipelining involves the sequence of bus operations that occurs during instruction execution. The instruction—fetch, decode, operand—fetch, execute pipeline is essentially invisible to the user, except in some cases where the pipeline must be broken (such as for branch instructions). In the operation of the pipeline the instruction fetch, decode, operand fetch, and execute operations are independent which allow instruction executions to overlap. Thus, during any given cycle, one to four different instructions can be active, each at a different stage of completion, resulting in a four deep pipeline.

Reset (RS-) is a non-maskable external interrupt that can be used at any time to put the processor **13**, **15** into a known state. Reset is typically applied after powerup when the machine is in an unknown state.

Driving the. RS- signal low causes the processor to terminate execution and forces the program counter **93** to zero. RS- affects various registers and status bits. At powerup, the state of the processor **13**, **15** is undefined. For correct system operation after powerup, a reset signal is asserted low for five clock cycles to reset the device **11**. Processor execution begins at location **0**, which normally contains a B (BRANCH) statement to direct program execution to the system initialization routine.

Upon receiving an RS-signal, the following actions take place:

1) A logic 0 is loaded into the CNF (configuration control) bit in status register ST**1**, mapping all on-chip data RAM into data address space.

2) The Program Counter (PC) is set to 0, and the address bus A15–A0 is driven with all zeros while RS- is low.

3) All interrupts are disabled by setting the INTM (interrupt mode) bit to 1. (Note that RS- is non-maskable). The interrupt flag register (IFR) is cleared.

4) Status bits: ("—" means "loaded into")

0—OV,1—XF,1—SXM,0—PM,1—HM,0—BRAF,0—TRM,0—NDX,

0—CENB**1**,0—CENB**2**, Inverse of TxM—MP/MC- and RAM,

0—OVLY, 0—IPTR, and 1—C.

(The remaining status bits remain undefined and should be initialized appropriately).

5) The global memory allocation register (GREG) is cleared to make all memory local.

6) The RPTC (repeat counter) is cleared.

7) The IACK- (interrupt acknowledge) signal is generated in the same manner as a maskable interrupt.

8) A synchronized reset signal SRESET- is sent to the peripheral circuits to initialize them.

Execution starts from location 0 of program memory when the RS- signal is taken high. Note that if RS- is asserted while in the hold mode, normal reset operation occurs internally, but all buses and control lines remain in the high-impedance state. Upon release of HOLD- and RS-, execution starts from location zero.

There are four key status and control registers for the processor core. ST**0** and ST**1** contain the status of various conditions while PMST and CBCR contain extra status and control information for control of the enhanced features of the processor core. These registers can be stored into data memory and loaded from data memory, thus allowing the status of the machine to be saved and restored for subroutines. Each of these registers has an associated one-deep stack for automatic context saves when an interrupt trap is taken. The stack is automatically popped upon a return from interrupt.

The PMST and CBCR registers reside in the memory-mapped register **85** space in page zero of data memory space. Therefore they can be acted upon directly by the CALU and the PLU. They can be saved the same as any other data memory location.

ST**0** and ST**1** are written to using the LST and LST**1** instructions respectively and read from using the SST and SST**1** instructions (with the exception of the INTM bit that is not affected by the LST instruction).

Unlike the PMST and CBCR registers, the ST**0** and ST**1** registers do not reside in the memory map and therefore are not handled using the PLU instructions. The individual bits

of these registers can be set or cleared using the SETC and CLRC instructions. For example, the sign-extension mode is set with SETC SXM or cleared with CLRC SXM.

Table A-4 defines all the status/control bits.

Table A-4 Status Register Field Definitions

FIELD FUNCTION

ARB Auxiliary Register Pointer Buffer. ST1 bits **15–13**. Whenever the ARP is loaded, the old ARP value is copied to the ARB except during an LST instruction. When the ARB is loaded via a LST1 instruction, the same value is also copied to the ARP.

ARP Auxiliary Register Pointer. STO bits **15–13**. This three-bit field selects the AR to be used in indirect addressing. When ARP is loaded, the old ARP value is copied to the ARB register.

ARP may be modified by memory-reference instructions when using indirect addressing, and by the LARP, MAR, and LST instructions. ARP is also loaded with the same value as ARB when an LST1 instruction is executed.

BRAF Block Repeat Active Flag. PXST bit **0**. This bit indicates whether (BRAF=1) or not (BRAF=0) block repeat is currently active. Writing a zero to this bit deactivates block repeat. BRAF is set to zero upon reset.

C Carry Bit. ST1 bit **9**. This bit is set to 1 if the result of an addition generates a carry, or reset to 0 if the result of a subtraction generates a borrow. Otherwise, it is reset after an addition or set after a subtraction, except if the instruction is ADD or SUB. ADD can only set and SUBH only reset the carry bit, but does not affect it otherwise. The single bit shift and rotate instructions also affect this bit, as well as the SETC, CLRC, LST1 instructions. Branch instructions are provided to branch on the status of C. C is set to 1 on a reset.

CAR1 Circular Buffer **1** Auxiliary Register. CBCR bits **2–0**. These three bits identify which auxiliary register is assigned to circular buffer **1**.

CAR2 Circular Buffer **2** Auxiliary Register. CBCR bits **6–4**. These three bits identify which auxiliary register is assigned to circular buffer **2**.

CENB1 Circular Buffer **1** Enable. CBCR bit **3**. This bit, when set to **1**, enables circular buffer **1**. When set to zero, disables circular buffer **1**. Set to zero upon reset.

CENB2 Circular Buffer **2** Enable. CBCR bit **7**. This bit, when set to 1, enables circular buffer **2**. When set to zero circular buffer **2** is disabled.

CBEN2 is set to zero upon reset. CNF On-chip RAM Configuration Control bit. ST1 bit **12**. If set to 0, the reconfigurable data RAM blocks are mapped to data space; otherwise, they are mapped to program space. The CNF may be modified by the CNFD, CNFP, and LST1 instructions. RE- resets the CNF to 0.

DP Data Memory Page Pointer. STO bits **8–0**. The 9-bit DP register is concatenated with the 7 LSBs of an instruction word to form a direct memory address of 16 bits. DP may be modified by the LST, LDP, and LDPK instructions.

FO Format bit. ST1 bit **3**. This bit is used to configure the serial port format.

FSM Frame Synchronous Mode bit. ST1 bit **5**. This bit is used in configuration of the framing mode of the serial port.

HM Hold Mode bit. ST1 bit **6**. When HM=1, the processor halts internal execution when acknowledging an active HOLD-. When HM=0, the processor may continue execution out of internal program memory but puts its external interface in a high-impedance state. This bit is set to 1 by reset.

INTM Interrupt Mode bit. ST**0** bit **9**. When set to 0, all unmasked interrupts are enabled. When set to 1, all maskable interrupts are disabled.

INTM is set and reset by the DINT and EINT instructions. RS- and IACK- also set INM.

INTM has no effect on the unmaskable RS- and NM1- interrupts. INTM is unaffected by the LST instruction.

IPTR Interrupt vector pointer PMST bits **15–11**. These five bits point to the 2K page where the interrupt vectors reside. This allows the user to remap interrupt vectors to RAM for boot loaded operations. At reset these bits are all set to zero. Therefore the reset vector always resides at zero in the program memory space.

MP/MC- MicroProcessor/Microcomputer bit, PMST bit **3**. When set to zero the on-chip ROM is enabled. When set to one the on-chip ROM is not addressable. This bit is set to the inverse of TXM at reset.

NDX Enable Extra Index Register. PMST bit **2**. When set to 0, the ARAU uses AR**0** for indexing and address compare. When set to 1, the ARAU uses INDX for indexing and ARCR for address compare. Upon reset, this bit is set to zero.

OV Overflow Flag bit. ST**0** bit **12**. As a latched overflow signal, OV is set to **1** when overflow occurs in the ALU. Once an overflow occurs, the OV remains set until a reset, BV, BNV, or LST instructions clears OV.

OVLY OVerLAY the on-chip program memory in data memory space. PMST bit **5**. If set to zero the memory is addressable in program space only. If set to one it is addressable in both program and data space. Set to zero at reset.

OVM Overflow Mode bit. ST**0** bit **11**. When set to 0, overflowed results overflow normally in the accumulator. When set to 1, the accumulator is set to either its most positive or negative value upon encountering an overflow. The SOVM and ROVM instructions set and reset this bit, respectively. LST may also be used to modify the OVM.

PM Product Shift Mode. ST1 bits **1–0**. If these two bits are 00, the multiplier's 32-bit product or buffer is loaded into the ALU with no shift. If PM=01, the PREG or BPR output is left-shifted one place and loaded into the ALU, with the LSB zero-filled. If PM=10, the PREG or BPR output is left-shifted by four bits and loaded into the ALU, with the LSBs zero-filled. PM=11 produces a right shift of six bits, sign-extended. Note that the PREG or BPR contents remain unchanged. The shift takes place when transferring the contents of the-PREG or BPR to the ALU. PM is loaded by the SPM and LSTI instructions. The PM bits are cleared by RS-.

RAM Enable/Disable on-chip RAM. PMST bit **4**. Set to inverse of TXM at reset. If set to zero the on-chip program RAM is disabled. If set to one the on-chip program RAM is enabled.

SXM Sign-Extension Mode bit. ST1 bit **10**. SXM=1 produces sign extension on data as it is passed into the accumulator through the scaling shifter. SXM=0 suppresses sign extension. SXM does not affect the definition of certain instructions; e.g., the ADDS instruction suppresses sign extension regardless of SXM. This bit is set and reset by the SSXM and RSXM instructions, and may also be loaded by LST1. SXM is set to 1 by reset.

TC Test/Control Flag bit. ST1 bit **11**. The TC bit is affected by the BIT, BITT, CMPR, LST1, NORM, CPLK, XPLK, OPLX, APLK, XPL, OPL, and APL instructions. The TC bit is set to a 1 if a bit tested by BIT or BITT is a 1, if a compare condition tested by CMPR exists between ARCR and another AR pointed to by ARP, if the

exclusive-OR function of the two MSBs of the accumulator is true when tested by a NORM instruction, if the long immediate value is equal to the data value on the CPLK instruction, or if the result of the logical function (XPLK, OPLK, APLK, XPL, OPL or APL) is zero. Fourteen conditional branch, call and return instructions provide operations based upon the value of TC: BEZ, BBZD, BBNZ, BBNZD, CBZ, CBZD, CBNZ, CBNZD, REZ, RJBZD, RBNZ, RBNZD, CEBZ, and CEBNZ.

TRM Enable Multiple TREG's. PMST bit **1**. When TRM is set to zero, any write to any of TREGO, TREG**1** or TREG**2** writes to all three. When TRM is set to one, TREG**0**, TREG**1**, and TREG**2** are individually selectable. TRM is set to zero at reset.

TXM Transmit Mode Bit. ST**1** bit **2**. This bit is used in configuration of the transmit clock pin of the serial port.

XF XF pin status bit. ST**1** bit **4**. This bit indicates the current level of the external flag.

The repeat counter (RPTC) in registers **85** is a 16-bit counter, which when loaded with a number N, causes the next single instruction to be executed N+1 times. The RPTC can be loaded with.a number from 0 to 255 using the RPTK instruction or a number from 0 to 65535 using the RPT, RPTR, or RPTZ instructions. This results in a maximum of 65536 executions of a given instruction. RPTC is cleared by reset. Both the RPTR and the RPTZ instructions load a long immediate value into RPTC and the RPTZ also clears the PREG and ACC.

The repeat feature can be used with instructions such as multiply/accumulates (MAC/MACD), block. moves (BLKD/BLKP), I/O transfers (IN/OUT), and table read/writes (TBLR/TBLW). These instructions, although normally multi-cycle, are pipelined when using the repeat feature, and effectively become single-cycle instructions. For example, the table read instruction may take three or more cycles to execute, but when repeated, a table location can be read every cycle.

A block repeat feature provides zero overhead looping for implementation of FOR or DO loops. The function is controlled by three registers (PASR, PAER and BRCR) in registers **85** and the BRAF bit in the PMST. The Block Repeat Counter Register (BRCR) is loaded with a loop count of 0 to 65535. Then the RPTB (repeat block) instruction is executed, thus loading the Program Address Start Register (PASR) with the address of the instruction following the RPTB instruction and loading the Program Address End Register (PAER) with its long immediate operand. The long immediate operand is the address of the last instruction in the loop. The BRAF bit is automatically set active by the execution of the RPTB instruction so the loop starts. With each PC update, the PAER is compared to the PC. If they are equal the BRCR is decremented. If the BRCR is greater than or equal to zero, the PASR is loaded into the PC thus starting the loop over.

The equivalent to a WHILE loop can be implemented by setting the BR A bit to zero if the exit condition is met. If this is done, the program completes the current pass through the lop but not go back to the top. The bit must be set at least three instructions before the end of the loop to exit the current loop. Block repeat loops can be exited and returned to without stopping and restarting the loop. Subroutine calls and branches and interrupts do not necessarily affect the loop. When program control is returned to the loop, the loop execution is resumed.

Loops can be nested by saving the three registers PASR, PAER and BRCR prior to entry of an internal loop and restoring them upon completion of the internal loop and resetting of the BRAF bit. Since it takes a total of 12 cycles to save (6 cycles) and restore (6 cycles) the block repeat registers, smaller internal loops can be processed with the BANZD looping method that take two extra cycles per loop (i.e., if the loop count is less than **6** it may be more efficient to use the BANZD technique).

When operating in the powerdown mode, the processor core enters a dormant state and dissipates considerably less power than the power normally dissipated by the device. Powerdown mode is invoked either by executing an IDLE instruction or by driving the HOLD- input low while the HM status bit is set to one.

While in powerdown mode, all of the internal contents of processor **13**, **15** are maintained to allow operation to continue unaltered when powerdown mode is terminated. Powerdown mode, when initiated by an IDLE instruction, is terminated upon receipt of an interrupt. When powerdown mode is initiated via the HOLD- signal it is terminated when the HOLD- goes inactive.

The power requirements can be further lowered to the sub-milliamp range by slowing down or even stopping the input clock. RS- is suitably activated before stopping the clock and held active until the clock is stabilized when restarting the system. This brings the device back to a known state. The contents of most registers and all on-chip RAM remain unchanged. The exceptions include the registers modified by a device reset.

The Peripheral Logic Unit (PLU) **41** of FIG. **1**B is used to directly set, clear, toggle or test multiple bits in a control/status register or any data memory location. The PLU provides a direct logic operation path to data memory values without affecting the contents of the accumulator or product register. It is used to set or clear multiple control bits in a register or to test multiple bits in a flag register.

The PLU **41** operates by fetching one operand via data bus **111**D from data memory space, fetching the second from either long immediate on the program bus **101**D or a DBMR (Dynamic Bit Manipulation Register) **223** via a MUX **225**. The DBMR is previously loaded from data bus **111**D. Then the PLU executes its logic operation, defined by the instruction on the two operands. Finally, the result is written via data bus **111**D to the same data location that the first operand was fetched from.

The PLU allows the direct manipulation of bits in any location in data memory space. This direct bit-manipulation is done with by ANDing, oring, XORing or loading a **16**-bit long immediate value to a data location. For example, to initialize the CBCR (Circular Buffer Control Register) to use AR**1** for circular buffer **1** and AR**2** for circular buffer **2** but not enable the circular buffers, execute:

SPLK **021**h, CBCR Store Peripheral Long Immediate

To later enable circular buffers **1** and **2** execute:

OPLK **088**h, CBCR Set bit **7** and bit **3** in CBCR

Testing for individual bits in a specific register or data word is still done via the BIT instruction, however, a data word can be tested against a particular pattern with the CPLX (Compare Peripheral Long Immediate) instruction. If the data value is equal to the long immediate value, then the TC bit is set to one. If the result of any PLU instruction is zero then the TC bit is set.

The bit set, clear, and toggle functions can also be executed with a 16-bit dynamic register DBMR value instead of the long immediate value. This is done with the following three instructions: XPL (XOR DBMR register to data); OPL (OR DBMR register to data); and APL (AND DBMR Register to data).

The processor has sixteen external maskable user interrupts (INT**16**–INT**1**) available for external devices that

interrupt the processor. Internal interrupts are generated by the serial port (RINT and XINT), by the timer (TINT), by parity checkers (PNTL and PNTH), and by the software interrupt (TRAP) instruction. Interrupts are prioritized with reset (RS-) having the highest priority and INT15 having the lowest priority.

An interrupt control block **231** feeds program data bus **101**D. Vector locations and priorities for all internal and external interrupts are shown in Table A-5. The TRAP instruction, used for software interrupts, is not prioritized but is included here since it has its own vector location. Each interrupt address has been spaced apart by two locations so that branch instructions can be accommodated in those locations.

TABLE A-5

Interrupt Locations and Priorities

NAME	LOCATION DEC	LOCATION HEX	PRIORITY	FUNCTION
RS-	0	0	1 (highest)	EXTERNAL RESET SIGNAL
INT1-	2	2	3	EXTERNAL USER INTERRUPT #1
INT2-	4	4	4	EXTERNAL USER INTERRUPT #2
INT3-	6	6	5	EXTERNAL USER INTERRUPT #3
INT4-	8	8	6	EXTERNAL USER INTERRUPT #4
INT5-	10	A	7	EXTERNAL USER INTERRUPT #5
INT6-	12	C	8	EXTERNAL USER INTERRUPT #6
INT7-	14	E	9	EXTERNAL USER INTERRUPT #7
INT8-	16	10	10	EXTERNAL USER INTERRUPT #8
INT9-	18	12	11	EXTERNAL USER INTERRUPT #9
INT10-	20	14	12	EXTERNAL USER INTERRUPT #10
INT11-	22	16	13	EXTERNAL USER INTERRUPT #11
INT12-	24	18	14	EXTERNAL USER INTERRUPT #12
INT13-	26	1A	15	EXTERNAL USER INTERRUPT #13
INT14-	28	1C	16	EXTERNAL USER INTERRUPT #14
INT15-	30	IE	17	EXTERNAL USER INTERRUPT #13
INT16-	32	20	18	EXTERNAL USER INTERRUPT #14
TRAP	34	22	N/A	TRAP INSTRUCTION VECTOR
NMI	36	24	2	NON-MASKABLE INTERRUPT

In FIG. 1B, a Bus Interface Module BIM **241** is connected between data bus **111**D and program data bus **101**D. BIM **241** on command permits data transfers between buses **101**D and **111**D and increases the architectural flexibility of the system compared to either the classic Harvard architecture or Von Neumann architecture.

Inventive systems including processing arrangements and component circuitry made possible by improvements to the processor **13**, **15** are discussed next. For general purpose digital signal processing applications, these systems advantageously perform convolution, correlation, Hilbert transforms, Fast Fourier Transforms, adaptive filtering, windowing, and waveform generation. Further applications involving in some cases the general algorithms just listed are voice mail, speech vocoding, speech recognition, speaker verification, speech enhancement, speech synthesis and text-to-speech systems.

Instrumentation according to the invention provides improved spectrum analyzers, function generators, pattern matching systems, seismic processing systems, transient analysis systems, digital filters and phase lock loops for applications in which the invention is suitably utilized.

Automotive controls and systems according to the invention suitably provide engine control, vibration analysis, anti-skid braking control, adaptive ride control, voice commands, and automotive transmission control.

In the naval, aviation and military field, inventive systems are provided and improved according to the invention to provide global positioning systems, processor supported navigation systems, radar tracking systems, platform stabilizing systems, missile guidance systems, secure communications systems, radar processing and other processing systems.

Further systems according to the invention include computer disk drive motor controllers, printers, plotters, optical disk controllers, servomechanical control systems, robot control systems, laser printer controls and motor controls generally. Some of these control systems are applicable in the industrial environment as robotics controllers, auto assembly apparatus and inspection equipment, industrial drives, numeric controllers, computerized power tools, security access systems and power line monitors.

Telecommunications inventions contemplated according to the teachings and principles herein disclosed include echo cancellers, ADPCM transcoders, digital PBXs, line repeaters, channel multiplexers, modems, adaptive equalizers, DTXF encoders and DTXF decoders, data encryption apparatus, digital radio, cellular telephones, fax machines, loudspeaker telephones, digital speech interpolation (DSI) systems, packet switching systems, video conferencing systems and spread-spectrum communication systems.

In the graphic imaging area, further inventions based on the principles and devices and systems disclosed herein include optical character recognition apparatus, 3-D rotation apparatus, robot vision systems, image transmission and compression apparatus, pattern recognition systems, image enhancement equipment, homomorphic processing systems, workstations and animation systems and digital mapping systems.

Medical inventions further contemplated according to the present invention include hearing aids, patient monitoring apparatus, ultrasound equipment, diagnostic tools, automated prosthetics and fetal monitors, for example. Consumer products according to the invention include high definition television systems such as high definition television receivers and transmission equipment used at studios and television stations. Further consumer inventions include music synthesizers, solid state answering machines, radar detectors, power tools and toys and games.

It is emphasized that the system aspects of the invention contemplated herein provide advantages of improved system architecture, system performance, system reliability and economy.

For example, in FIG. **2**, an inventive industrial process and protective control system **300** according to the invention includes industrial sensors **301** and **303** for sensing physical variables pertinent to a particular industrial environment. Signals from the sensors **301** and **303** are provided to a signal processor device **11** of FIGS. **1**A and **1**B which include the PLU (parallel logic unit) improvement **41** of FIG. **1**B. An interface **305** includes register locations A, B, C, D, E, F, G and H and drivers (not shown). The register locations are connected via the drivers and respective lines **307** to an industrial process device driven by a motor **311**, relay operated apparatus controlled by relays **313** and various valves including a solenoid valve **315**.

In the industrial process and protective control environment, various engineering and economic considerations operate at cross purposes. If the speed or throughput of the industrial process is to be high, heavy burdens are placed on the processing capacity of device **11** to interpret the significance of relatively rapid changes occurring in real time as sensed by sensors **301** and **303**. On the other hand, the control functions required to respond to the real-world

conditions sensed by sensors **301** and **303** must also be accomplished swiftly. Advantageously, the addition of PLU **41** resolves conflicting demands on device **11**, with negligible additional costs when device **11** is fabricated to a single semiconductor chip. In this way, the industrial processing rate, the swiftness of protective control and the precision of control are considerably enhanced.

In FIG. **3**, an inventive automotive vehicle **321** includes a chassis **323** on which is mounted wheels and axles, an engine **325**, suspension **327**, and brakes **329**. An automotive body **331** defines a passenger compartment which is advantageously provided with suspension relative to chassis **323**.

An active suspension **335** augments spring and absorber suspension technique and is controlled via an interface **341** having locations for bits A, B, C, D, E, F, G, H, I, J, K, L, M and N. A parallel computation processor **343** utilizes computation units of the type disclosed in Figures IA and 1B and includes at least one parallel logic unit **41** connected to data bus **351**D and program data bus **361**D. Numerous sensors include sensors **371**, **373** and **375** which monitor the function of suspension **335**, engine operation, and anti-skid braking respectively.

An engine control system **381** is connected to several of the locations of interface **341**. Also an anti-skid braking control system **383** is connected to further bits of interface **341**. Numerous considerations of automotive reliability, safety, passenger comfort, and economy place heavy demands on prior automotive vehicle systems.

In the invention of FIG. **3**, automotive vehicle **321** is improved in any or all of these areas by virtue of the extremely flexible parallelism and control advantages of the invention.

The devices such as device **11** which are utilized in the systems of FIGS. **2** and **3** and further systems described herein not only address issues of increased device performance, but also solve industrial system problems which determine the user's overall system performance and cost.

A preferred embodiment device **11** executes an instruction in 50 nanoseconds and further improvements in semiconductor manufacture make possible even higher instruction rates. The on-chip program memory is RAM based and facilitates boot loading of a program from inexpensive external memory. Other versions are suitably ROM based for further cost reduction.

An inventive digitally controlled motor system **400** of FIG. **4** includes a digital controller **401** having a device **11** of FIGS. **1**A and **1**B. Digital controller **401** supplies an output u(n) to a zero order hold circuit ZOH **403**. ZOH **403** supplies control output u(t) to a DC servomotor **405** in industrial machinery, home appliances, military equipment or other application systems Genvironment. Connection of motor **405** to a disk drive **406** is shown in FIG. **4**.

The operational response of servomotor **405** to the input u(t) is designated y(t). A sensor **407** is a transducer for the motor output y(t) and feeds a sampler **409** which in its turn supplies a sampled digitized output y(n) to a subtractor **411**. Sampler **409** also signals digital controller **401** via an interrupt line INT-. A reference input r(n) from human or automated supervisory control is externally supplied as a further input to the subtracter **411**. An error difference e(n) is then fed to the digital controller **401** to close the loop. Device **11** endows controller **401** with high loop bandwidth and multiple functionality for processing and control of other elements besides servomotors as in FIG. **2**. Zero-overhead interrupt context switching in device **11** additionally enhances the bandwidth and provides an attractive alternative to polling architecture.

In FIG. **5**, a multi-variable state controller **421** executes advanced algorithms utilizing the device **11** processor. State controller **421** receives a reference input r(n) and supplies an output u(n) to a motor **423**. Multiple electrical variables (position x1, speed x2, current x3 and torque x4) are fed back to the state controller **421**. Any one or more of the four variables x1–x4 (in linear combination for example) are suitably controlled for various operational purposes. The system can operate controlled velocity or controlled torque applications, and run stepper motors and reversible motors.

In FIG. **6**, a motor **431** has its operation sensed and sampled by a sampler **433**. A processor **435** including device **11** is interrupt driven by sampler **433**. Velocity information determined by unit **433** is fed back to processor **435** improved as described in connection with FIGS. **1**A and **1**B. Software in program memory **61** of FIG. **1**A is executed as estimation algorithm process **437**. Process **437** provides velocity, position and current information to state controller process **439** of processor **435**. A digital output u(n) is supplied as output from state controller **439** to a zero order hold circuit **441** that in turn drives motor **431**.

The motor is suitably a brushless DC motor with solid state electronic switches associated with core, coils and rotor in block **431**. The systems of FIGS. **4**-**6** accommodate shaft encoders, optical and Hall effect rotor position sensing and back emf (counter electromotive force) sensing of position from windings.

In FIG. **7**, robot control system **451** has a motor-driven grasping mechanism **453** at the end of a robot arm **455**. Robot arm **455** has a structure with axes of rotation **457.1**, **457.2**, **457.3** and **457.4** Sensors and high response accurately controllable motors are located on arm **455** at articulation points **459.1**, **459.2**, **459.3** and **459.4**.

Numerous such motors and sensors are desirably provided for accurate positioning and utilization of robot arm mechanism **455**. However, the numerous sensors and motors place conflicting demands on the system as a whole and on a controller **461**. Controller **461** resolves these system demands by inclusion of device **11** of FIGS. **1**A and **1**B and interrupt-driven architecture of system **451**. Controller **461** intercommunicates with an I/O interface **463** which provides analog-to-digital and digital-to-analog conversion as well as bit manipulation by parallel logic unit **41** for the robot arm **455**. The interface **463** receives position and pressure responses from the navigation motors **467** and sensors associated with robot arm **455** and grasping mechanism **453**. Interfacer **463** also supplies control commands through servo amplifiers **465** to the respective motors **467** of robot arm **455**.

Controller **461** has associated memory **467** with static RAM (SRAM) and programmable read only memory (PROM). Slower peripherals **469** are associated with controller **471** and they are efficiently accommodated by the page boundary sensitive wait state features of controller **461**. The controller **461** is also responsive to higher level commands supplied to it by a system manager CPU **473** which is responsive to safety control apparatus **475**. System manager **473** communicates with controller **461** via I/O and RS **232** drivers **475**.

The digital control systems according to the invention make possible performance advantages of precision, speed and economy of control not previously available. For another example, disk drives include information storage disks spun at high speed by spindle motor units. Additional controls called actuators align read and write head elements relative to the information storage disks.

The preferred embodiment can even provide a single chip solution for both actuator control and spindle motor control

as well as system processing and diagnostic operations. Sophisticated functions are accommodated without excessively burdening controller **461**. A digital notch filter can be implemented in controller **461** to cancel mechanical resonances. A state estimator can estimate velocity and current. A Kalman filter reduces sensor noise. Adaptive control compensates for temperature variations and mechanical variations. Device **11** also provides on-chip PWM pulse width modulation outputs for spindle motor speed control. Analogous functions in tape drives, printers, plotters and optical disk systems are readily accommodated. The inventive digital controls provide higher speed, more precise speed control, and faster data access generally in I/O technology at comparable costs, thus advancing the state of the art.

In missile guidance systems, the enhanced operational capabilities of the invention provide more accurate guidance of missile systems, thereby reducing the number of expensive missiles required to achieve operational objectives. Furthermore, equivalent performance can be attained with fewer processor chips, thus reducing weight and allowing augmented features and payload enhancements

In FIG. **8**, a satellite telecommunication system according to the invention has first stations **501** and **503** communicating by a satellite transmission path having a delay of **250** milliseconds. A far end telephone **505** and a near end telephone **507** are respectively connected to earth stations **501** and **503** by hybrids **509** and **511**. Hybrids **509** and **511** are delayed eight milliseconds ;relative to the respective earth stations **501** and **503**. Accordingly, echo cancellation is necessary to provide satisfactory telecommunications between far end telephone **505** and near end telephone **507**. Moreover, the capability to service numerous telephone conversation circuits at once is necessary. This places an extreme processing burden on telecommunications equipment.

In FIG. **9**, a preferreed embodiment echo canceller **515** is associated with each hybrid such as **511** to improve the transmission of the communications circuit. Not only does device **11** execute echo cancelling algorithms at high speed, but it also economically services more satellite communications circuits per chip.

Another system embodiment is an improved modem. In FIG. **10**, a process diagram of operations in device **11** programmed as a modem transmitter includes a scrambling step **525** followed by an encoding step **527** which provides quadrature digital signals $I[nT_b]$ and $Q[nT_b]$ to interpolation procedures **529** and **531** respectively. Digital modulator computations **533** and **535** multiply the interpolated quadrature signals with prestored constants from read only memory (ROM) that provide trigonometric cosine and sine values respectively. The modulated signals are then summed in a summing step **537**. A D/A converter connected to device **11** converts the modulated signals from digital to analog form in a step **539**. Gain control by a factor G1 is then performed in modem transmission and sent to a DAA.

In FIG. **11**, a modem receiver using another device **11** receives analog communications signals from the DAA. An analog-to-digital converter A/D **521** digitizes the information for a digital signal processor employing device **11**. High rates or digital conversion place heavy burdens on input processing of prior processors. Advantageously, DSP **11** provides zero-overhead interrupt context switching for extremely efficient servicing of interrupts from digitizing elements such as A/D **521** and at the same time has powerful digital signal processing coputational facility for executing modem algorithms. The output of device **11** is supplied to a universal synchronous asynchronous receiver transmitter (USART) **523** which supplies an output D[nT].

In FIG. **12**, a process diagram of modem reception by the system of FIG. **11** involves automatic gain control by factor G2 upon reception from the DAA supplying a signal s(t) for analog-to-digital conversion at a sampling frequency fs. The digitized signal is s[nTs] and is supplied for digital processing involving first and second bandpass filters implemented by digital filtering steps BPF**1** and BPF**2** followed by individualized automatic gain control. A demodulation algorithm produces two demodulated signals I'[nTs] and Q'[nTs]. These two signals I' and Q' used for carrier recovery fed back to the demodulation algrithm. Also I' and Q' are supplied to a decision algorithm and operated in response to clock recovery. A decoding process **551** follows the decision algorithm. Decoding **551** is followed by a descrambling algorithm **555** that involves intensive bit manipulation by PLU **41** to recover the input signal d[nT].

As shown in FIG. **12**, the numerous steps of the modem reception algorithm are advantageously accomplished by a single digital signal processor device **11** by virtue of the intensive numerical computation capabilities and the bit manipulation provided by PLU **41**.

In FIG. **13**, computing apparatus **561** incorporating device **11** cooperates with a host computer **563** via an interface **565**. High capacity outboard memory **567** is interfaced to computer **561** by interface **569**. The computer **561** advantageously supports two-way pulse code modulated (PCX) communication via peripheral latches **571** and **573**. Latch **571** is coupled to a serial to parallel converter **575** for reception of PCX communications from external apparatus **577**. Computer **561** communicates via latch **573** and a parallel to serial unit **579** to supply a serial PCM data stream to the external apparatus **577**.

In FIG. **14**, a video imaging system **601** includes device **11** supported by ROM **603** and RAM **605**. Data gathering sensors **607**.1 through **607**.n feed inputs to a converter **609** which then supplies voluminous digital data to device **11**. FIG. **14** highlights ALU **21** accumulator **23**, multiplier array **53**, product register **51** and has an addressing unit including ARAU **123**. A control element **615** generally represents decoder PLA **221** and pipeline controller **225** of Figure IA. On-chip I/O peripherals (not shown) communicate with a bus **617** supplying extraordinarily high quality output to a video display unit **619**. Supervisory input and output I/O **621** is also provided to device **11**.

Owing to the advanced addressing capabilities in device **11**, control **615** is operable on command for transferring the product from product register **51** directly to the addressing circuit **123** and bypassing any memory locations during the transfer. Because of the memory mapping, any pair of the computational core-registers of FIGS. 1A and 1B are advantageously accessed to accomplish memory-bypass transfers therebetween via data bus **111**D, regardless of arrow directions to registers on those Figures. Because the multiplication capabilities of device **11** are utilized in the addressing function, the circuitry establishes an array in the electronic memory **605** wherein the array has entries accessible in the memory with a dimensionality of at least three. The video display **619** displays the output resulting from multi-dimensional array processing by device **11**. It is to be understood, of course, that the memory **605** is not in and of itself necessarily multi-dimensional, but that the addressing is rapidly performed by device **11** so that information is accessible on demand as if it were directly accessible by variables respectively representing multiple array dimensions. For example, a three dimensional cubic array having

address dimensions A1, A2 and A3 can suitably be addressed according to the equation $N^2 \times A3 + N \times A2 + A1$. In a two dimensional array, simple repeated addition according to an index count from register **199** of FIG. **1A** is sufficient for addressing purposes. However, to accommodate the third and higher dimensions, the process is considerably expedited by introducing the product capabilities of the multiplier **53**.

FIGS. **15** and **16** respectively show function-oriented and hardware block-oriented diagrams of video processing systems according to the invention. Applications for these inventive systems provide new workstations, computer interfaces, television products and high definition television (HDTV) products.

In FIG. **15**, a host computer **631** provides data input to numeric processing by device **11**. Video pixel processing operations **633** are followed by memory control operations **635**. CRT control functions **637** for the video display are coordinated with the numeric processing **639**, pixel processing **633** and memory control **635**. The output from memory control **635** operations supplies frame buffer memory **641** and then a shift register **643**. Frame buffer memory and shift register **641** and **643** are suitably implemented by a Texas Instruments device TMS 4161. A further shift register **645** supplies video information from shift register **643** to a color palette **647**. Color palette **647** drives a display **649** which is controlled by CRT control **637**. The color palette **647** is suitably a TMS 34070.

In FIG. **16**, the host **631** supplies signals to a first device **11** operating as a DSP microprocessor **653**. DSP **653** is supported by memory **651** including PROM, EPROM and SRAM static memory. Control, address and data information are supplied by two-way communication paths between DSP **653** and a second device **11** operating as a GSP (graphics signal processor) **655**. GSP **655** drives both color palette **647** and display interface **657**. Interface **657** is further driven by color palette **647**. Display CRT **659** is driven by display interface **657**. It is to be understood that the devices **11** and the system of FIG. **16** in general is operated at an appropriate clock rate suitable to the functions required. Device **11** is fabricated in micron level and sub-micron embodiments to support processing speeds needed for particular applications. It is contemplated that the demands of high definition television apparatus for increased processing. power be met not only by use of higher clock rates but also by the structural improvements of the circuitry disclosed herein.

In FIG. **17**, an automatic speech recognition system according to the invention has a microphone **701**, the output of which is sampled by a sample-and-hold (S/H) circuit **703** and then digitally converted by A/D circuit **705**. An interrupt-driven fast Fourier transform processor **707** utilizes device **11** and converts the sampled time domain input from microphone **701** into a digital output representative of a frequency spectrum of the sound. This processor **707** is very efficient partly due to the zero-overhead interrupt context switching feature, conditional instructions and auxiliary address registers mapped into memory address space as discussed earlier.

Processor **707** provides each spectrum to a speech recognition DSP **709** incorporating a further device **11**. Recognition DSP **709** executes any appropriately now known or later developed speech recognition algorithm. For example, in a template matching algorithm, numerous computations involving multiplications, additions and maximum or minimum determinations are executed. The device **11** is ideally suited to rapid execution of such algorithms by virtue of its series maximum/minimum function architecture. Recognition DSP **709** supplies an output to a system bus **711**. ROM **713** and RAM **715** support the system efficiently because of the software wait states on page boundaries provided by recognition DSP **709**. Output from a speech synthesizer **717** that is responsive to speech recognition DSP **709** is supplied to a loudspeaker or other appropriate transducer **719**.

System I/O **721** downloads to document production devices **723** such as printers, tapes, hard disks and the like. A video cathode ray tube (CRT) display **725** is fed from bus **711** as described in connection with FIGS. **15** and **16**. A keyboard **727** provides occasional human supervisory input to bus **711**. In industrial and other process control applications of speech recognition, a control interface **729** with a further device **11** is connected to bus **711** and in turn supplies outputs for motors, valves and other servomechanical elements **731** in accordance with bit manipulation and the principles and description of FIGS. **2**, **3**, **4**, **5**, **6** and **7** hereinabove.

In speech recognition-based digital filter hearing aids, transformed speech from recognition DSP **709** is converted from digital to analog form by a D/A converter **735** and output through a loudspeaker **737**. The same chain of blocks **701**, **703**, **705**, **707**, **709**, **735**, **737** is also applicable in telecommunications for speech recognition-based equalization, filtering and bandwidth compression.

In advanced speech processing systems, a lexical access processor **739** performs symbolic manipulations on phonetic element representations derived from the output of speech recognition DSP **709** and formulates syllables, words and sentences according to any suitable lexical access algorithm.

A top-down processor **741** performs a top-down processing algorithm based on the principle that a resolution of ambiguities in speech transcends the information contained in the acoustic input in some cases. Accordingly, non-acoustic sensors, such as an optical sensor **743** and a pressure sensor **745** are fed to an input system **747** which then interrupt-drives pattern recognition processor **749**. Processor **749** directly feeds system bus **711** and also accesses top-down processor **741** for enhanced speech recognition, pattern recognition, and artificial intelligence applications.

Device **11** substantially enhances the capabilities of processing at every level of the speech recognition apparatus of FIG. **17**, e.g., blocks **707**, **709**, **717**, **721**, **725**, **729**, **739**, **741**, **747** and **749**.

FIG. **18** shows a vocoder-modem system with encryption for secure communications. A telephone **771** communicates in secure mode over a telephone line **773**. A DSP microcomputer **773** is connected to telephone **771** for providing serial data to a block **775**. Block **775** performs digitizing vocoder functions in a section **777**, and encryption processing in block **781**. Modem algorithm processing in blocks **779** and **783** is described hereinabove in connection with FIGS. **10** and **12**. Block **783** supplies and receives serial data to and from A/D, D/A unit **785**. Unit **785** provides analog communication to DAA **787**. The substantially enhanced processing features of device **11** of FIGS. A and 1B make possible a reduction in the number of chips required in block **775** so a cost reduction is made possible in apparatus according to FIG. **18**. In some embodiments, more advanced encryption procedures are readily executed by the remarkable processing power of device **11**. Accordingly, in FIG. **18**, device **11** is used either to enhance the functionality of each of the functional blocks or to provide comparable functionality with fewer chips and thus less overall product cost.

Three Texas Instruments DSPs are described in the TMS 320C1x User's Guide and TMS 320C2x User's Guide and Third Generation TMS **320** User's Guide, all of which are

incorporated herein by reference. Also, coassigned U.S. Pat. Nos. 4,577,282 and 4,713,748 are incorporated herein by reference.

FIG. **19** illustrates the operations of the parallel logic unit **41** of FIG. **1**B. The parallel logic unit (PLU) allows the CPU to execute logical operations directly on values stored in memory without affecting any of the registers such as the accumulator in the computation unit **15**. The logical operations include setting, clearing or toggling any number of bits in a single instruction. In the preferred embodiment, the PLU accomplishes a read-modify-write instruction in two instruction cycles. Specifically, PLU **41** accesses a location in RAM **25** either on-chip or off-chip, performs a bit manipulation operation on it, and then returns the result to the location in RAM from which the data was obtained. In all of these operations, the accumulator is not affected. The product register is not affected. The accumulator buffer and product register register buffers ACCB and BPR are not affected. Accordingly, time consuming operations which would substantially slow down the computation unit **15** are avoided by the provision of this important parallel logic unit PLU **41**. Structurally, the PLU is straight-through logic from its inputs to its outputs which is controlled by decoder PLA **221**, enabling and disabling particular gates inside the logic of the PLU **41** in order to accomplish the instructions which are shown below.

APL,K and the DBMR or a constant with data memory value

CPL,K Compare DBMR or constant with data memory value

OPL,K or DBMR or a constant with data memory value

SPLX,X store long immediate to data memory location

XPL,K XOR DBMR or a constant with data memory value

Bit manipulation includes operations of: 1) set a bit; 2) clear a bit; 3) toggle a bit; and 4) test a bit and branch accordingly. The PLU also supports these bit manipulation operations without affecting the contents of any of the CPU registers or status bits. The PLU also executes logic operations on data memory locations with long immediate values.

In FIG. **19**, Part A shows a memory location having an arbitrary number of bits X. In Part B, the SPLK instruction allows any number of bits in a memory word to be written into any memory location. In Part C, the OPL instruction allows any number of bits in a memory word to be set to one without affecting the other bits in the word. In Part D, the APL instruction allows any number of bits in a memory word to be cleared or set to zero, without affecting the other bits in the word. In Part E, the XPL instruction allows any number of bits in a memory word to be toggled without affecting the other bits in the word. In Part F, the CPL instruction compares a given word (e.g., 16 bits) against the contents of an addressed memory location without modifying the addressed memory location. The compare function can also be regarded as a non-destructive exclusive OR (XOR) for a compare on a particular memory location. If the comparison indicates that the given word is equal to the addressed memory word, then a TC bit is set to one. The TC bit is bit **11** of the ST1 register in the registers **85** of FIG. **1**B. A test of an individual bit is performed by the BIT and BITT instructions.

Structurally, the presence of PLU instructions means that decoder PLA **221** of FIG. **1**A and the logic of PLU **41** include specific circuitry. When the various PLU instructions are loaded into the instruction register (IR), they are decoded by decoder PLA **221** into signals to enable and disable gates in the logic of PLU **41** so that the operations which the instructions direct are actually executed.

To support the dynamic placement of bit patterns, the instructions execute basic bit operations on a memory word with reference to the register value in the dynamic bit manipulation register DBMR **223** instead of using a long immediate value. The DBMR is memory mapped, meaning structurally that there is decoding circuitry **121** (FIG. **1**B) which allows addressing of the DBMR **223** from data address bus **111**A. A suffix K is appended to the instruction (e.g. APLK) to indicate that the instruction operates on a long immediate instead of DBMR. Absence of the suffix (e.g. APL) indicates that the instruction operates on the DBMR. Selection of the DBMR is accomplished by MUX **225** of FIG. **1**B which has its select input controlled from decoder PLA **221** with pipeline timing controlled by pipeline controller **225**.

A long immediate is a value coming from the program data bus as part of an instruction. "Immediate" signifies that the value is coming in from the program data bus. "Long immediate" means that a full word-wide value is being supplied.

A long immediate often is obtained from read-only memory (ROM) and thus is not alterable. However, when it is desired to have the logical operation be alterable in an instruction sequence, the dynamic bit manipulation bit register is provided for that purpose.

PLU **41** allows parallel bit manipulation on any location in data memory space. This permits very high efficiency bit manipulation which accommodates the intensive bit manipulation requirements of the control field. Bit manipulation of the invention is readily applicable to automotive control such as engine control, suspension control, anti-skid braking, and process control, among other applications. Bit manipulations can switch on and off at relay by setting a bit on or off, turn on an engine, speed up an engine, close solenoids and intensify a signal by stepping a gain stage to a motor in servo control. Complicated arithmetic operations which are needed for advanced microcontrol applications execute on device **11** without competition by bit manipulation operations.

Further applications of bit manipulation include scrambling in modems. If certain bit patterns fail to supply frequency or phase changes often enough in the modem, it is difficult or impossible to maintain a carrier in phase clock loops and modem receivers. The bit patterns are scrambled to force the bits to change frequently enough. In this way, the baud clock and carrier phase lock loop in the modem are configured so that there is adequate but not excessive energy in each of the digital filters. Scrambling involves XORing operations to a serial bit stream. The PLU **41** does this operation extremely efficiently. Since the other CPU registers of device **11** are not involved in the PLU operations, these registers need not be saved when the PLU is going to execute its instructions. In the case of the scrambling operation, the bits that are XORed. into data patterns are a function of other bits so it takes more than one operation to actually execute the XORs that are required in any given baud period. With the parallel logic unit, these operations can be performed concurrently with computatical operations without having to use the register resources.

As thus described, the PLu together with instruction decoder **221** act as an example of a logic circuit, connected to the program bus for receiving instructions and connected to the data bus, for executing logic operations in accordance with at least some of the instructions. The logic operations affect at least one of the data memory locations independently of the electronic computation unit without affecting the accumulator. In some of the instructions, the logic

operations include an operation of setting, clearing or toggling particular bits to one in a data word at a selected data memory location without affecting other bits in the data word at the selected data memory location.

With the DBMR **223**, a further logic circuit improvement is provided so that PLU **41** has a first input connected for receiving data from the data bus, an output for sending data to the data bus and a second input selectively operable to receive a word either from the data bus or program bus. The multiplexer **225** acts as a selectively operable element. For example, the contents of any addressable register or memory location can be stored to the DBMR**4** when MUX **275** selects the DBMR, then the PLU sends to data bus **111**D the contents of a word from data bus **111**D modified by a logical operation based on the DBMR such as setting, clearing or toggling. When MUX **225** selects program data bus **101**D, a long immediate constant is selected, on which to base the logical operation.

Turning now to the subject of interrupt management and context switching, FIG. **20** illustrates a system including DSP device **11** having four interfaces **801**, **803**, **805** and **807**. An analog signal from a sensor or transducer is converted by A/D converter **809** into digital form and supplied to DSP **11** through interface **801**. When each conversion is complete an interrupt signal INT1- is supplied from analog to digital converter **809** to DSP **11**. DSP **11** is supported by internal SRAM **811**, by ROM and EPROM **813** and by external memory **815** through interface **803**. The output of DSP **11** is supplied to a digital-to-analog converter **817** for output and control purposes via interface **807**. An optional host computer **819** is connected to an interrupt input INT2- of DSP **11** and communicates data via interface **805**. Other interrupt-based systems herein are shown in FIGS. **4**, **6**, **11**, **14** and **17**.

Operations of device **11** on interrupt or other context change are now discussed. Referring to FIGS. **1**A and **1**B, it is noted that several of the registers are drawn with a background rectangle. These registers are TREG2 **195**, TREG1 **81**, TREGO **49** , BPR **185**, PREG **51**, ACC **23**, ACCB **31**, INDX **143**, ARCR **159**, STO, ST1, and PMST. These registers have registers herein called counterpart registers associated with them. Any time an interrupt or other context change occurs, then all of the aforementioned registers are automatically pushed onto a one-deep stack. When there is a return from interrupt or a return, from the context change, the same registers are automatically restored by popping the one-deep stack.

Advantageously, the interrupt service routines are handled with zero time overhead on the context save or context switching. The registers saved in this way are termed "strategic registers". These are the registers that would be used in an interrupt service routine and in preference to using any different register in their place.

If a context save to memory were executed register-by-register to protect the numerous strategic registers, many instruction cycles would be consumed. Furthermore, the relative frequency at which these context save operations occurs depends on the application. In some applications with 100 KHz sampling rates in FIG. **20**, the frequency of interrupts is very high and thus the cycles of interrupt context save overhead could, without the zero-overhead improvement be substantial. By providing the zero-overhead context switching feature of the preferred embodiment, the interrupt service routine cycle count can be reduced to less than half while obtaining the same functionality. It is advantageous to execute on the order of 100,000 samples per second in multiple channel applications of a DSP or to process a single channel with a very high sampling frequency such as 50 KHz or more. The remarks just made are also applicable to subroutine calls, function calls and other context switches.

When an interrupt occurs, status registers are automatically pushed onto the one-deep stack. In support of this feature, there is an additional instruction, return from interrupt (RETI), that automatically pops the stacks to restore the main routine status. The preferred embodiment also has an additional return instruction (RETE) that automatically sets a global interrupt enable bit, thus enabling interrupts while popping the status stack. An instruction designated as delayed return with enable (RETED) protects the three instructions following the return from themselves being interrupted.

The preferred embodiment has an interrupt flag register (IFR) mapped into the memory space. The user can read the IPR by software polling to determine active interrupts and can clear interrupts by writing to the IFR.

Some applications are next noted in which the zero-overhead context switching feature is believed to be particularly advantageous. Improved disk drives are thus made to be faster and accommodate higher information density with greater acceleration and deceleration and faster read alignment adjustment. The processor can service more feedback points in robotics. In modems, a lower bit error rate due to software polling of interrupts is made possible. Vocoders in their encoding are made to have higher accuracy and less bit error. Missile guidance systems have more accurate control and require fewer processors. Digital cellular phones are similarly improved.

The zero-overhead context save feature saves all strategic CPU registers when an interrupt is taken and restores them upon return from the service routine without taking any machine cycle overhead. This frees the interrupt service routine to use all of the CPU resources without affecting the interrupted code.

FIG. **21** shows a block diagram of device **11** in which the subject matter of FIGS. **1**A and **1**B is shown as the CPU block **13**, **15** in FIG. **21**. A set of registers are shown broken out of the CPU block and these are the strategic registers which have a one-deep stack as described hereinabove.

FIG. **21** is useful in discussing the overall system architecture of the semiconductor chip. A set of interrupt trap and vector locations **821** reside in program memory space. When an interrupt routine in program memory **61** of FIGS. **1**A and **21** is to be executed, the interrupt control logic **231** of FIG. **21** causes the program counter **93** of FIG. **1**A to be loaded with appropriate vector in the interrupt locations **821** to branch to the appropriate interrupt service routine. Two core registers IFR and IMR are an interrupt flag register and interrupt mask register respectively. The interrupt flag register gives an indication of which specific interrupts are active. The interrupt mask register is a set of bits by which interrupts to the CPU can be disabled by masking them. For example, if there is an active interrupt among the interrupts INT2-, INT1-, and INT0-, then there will be a corresponding bit in the IFR that is set for a "1". The flag is cleared by taking an interrupt trap by which it will automatically be cleared. Otherwise, the interrupt is cleared by ORing a one into the respective interrupt flag register that clears the interrupt. All active interrupt flags can be cleared at once also.

The program and data buses **101** and **111** are diagrammatically combined in FIG. **21** and terminate in peripheral ports **831** and **833**. Peripheral port **833** provides a parallel interface. Port **831** provides an interface to the TI bus and serial ports for device **11**.

FIGS. **22**, **23** and **24** illustrate three alternative circuits for accomplishing zero-overhead interrupt context switching. It should be understood all the strategic registers are context-switched in parallel simultaneously, and therefore the representation of all the registers by single flip flops is a diagrammatic technique.

In FIGS. **22** and **23**, the upper register and lower register represent the foreground and background rectangles of each of the strategic registers of FIGS. **1**A and **1**B. FIG. **24** shows the parallelism explicitly.

In FIG. **22**, a main register **851** has its data D input selectively supplied by a MUX **853**. MUX **853** selectively connects the D input of register **851** to either parallel data lines A or parallel data lines B. Lines B are connected to the Q output of a counterpart register **855**. Main register **851** has a set of Q output lines that are respectively connected to corresponding D inputs of the counterpart register **855**.

In an interpretive example, the arrow marked input for line A represents the results of computations by ALU **21**, and accumulator **23** includes registers **851** and **855**. The output of main register **851** of FIG. **22** interpreted as accumulator **23** is supplied, for example, to post scaler **181** of FIG. **1**A. It should be understood, however, that the register **851** is replicated as many times as required to correspond to each of the strategic registers for which double rectangles are indicated in FIGS. **1**A and **1**B.

In FIG. **22**, each of the registers **851** and **855** has an output enable (OE) terminal. An OR gate **857** supplies a clock input of main register **851**. OR gate **857** has inputs for CPU WRITE and RETE. RETE also feeds a select input of MUX **853** and also the OE output enable terminal of counterpart register **855**. Main register **851** has its OE terminal connected to the output of an OR gate **859**, the inputs of which are connected to interrupt acknowledge IACK and CPU READ. IACK also clocks counterpart register **855** and all other counterpart registers as indicated by ellipsis.

In operation, in the absence of a return from interrupt (RETE low), MUX **853** selects input line A for main register **851**. Upon occurrence of CPU WRITE, main register **851** clocks the input from the CPU core into its D input. The CPU accesses the contents of register **851** when a CPU READ occurs at OR gate **859** and activates OE.

When an interrupt occurs and is acknowledged (IACK) by device **11**, the-output Q of register **851** is enabled and the counterpart register **855** is clocked, thereby storing the Q output of main register **851** into register **855**. As the interrupt service routine is executed, input lines A continue to be clocked by CPU WRITE into main register **851**. When the interrupt is completed, RETE goes low, switching XUX **853** to select lines B and activating line OE of counterpart register **855**. RETE also clocks register **851** through OR gate **857** to complete the transfer and restore the main routine information to main register **851**. Then upon completion of the return from interrupt RETE goes low reconnecting main register **851** to input lines A via MUX **853**. In this way, the context switching is completed with zero overhead.

FIG. **22** thus illustrates first and second registers connected to an electronic processor. The registers participate in one processing context (e.g. interrupt or subroutine) while retaining information from another processing context until a return thereto. MUX **853** and the gates **857** and **859** provide an example of a context switching circuit connected to the first and second registers operative to selectively control input and output operations of the registers to and from the electronic processor, depending on the processing context. The electronic processor such as the CPU **13**, **15** core of FIGS. **1**A and **1**B is responsive to a context signal such as interrupt INT- and operable in the alternative processing context identified by the context signal.

FIG. **23** illustrates a bank switching approach to zero overhead context switching. A main register **861** and a counterpart register **863** have their D inputs connected to a demultiplexer DMUX **865**. The Q outputs of registers **861**and **863** are connected to respective inputs of a MUX **867**. Input from the CPU core is connected to the DMUX **865**. Output back to the CPU core is provided from MUX **867**. Both select lines from XUXes **865** and **867** are connected to a line which goes active when an interrupt service routine ISR is in progress.

In this way, in a main routine, only register **861** is operative. During the interrupt service routine, register **863** is operated while register **861** holds contents to which operations are to return. A pair of AND gates **871** and **873** also act to activate and deactivate registers **861** and **863**. A CPU WRITE qualifies an input of each AND gate **871** and **873**. The outputs of AND gates **871** and **873** are connected to the clock inputs of registers **863** and **861** respectively. In a main routine with ISR low, register **873** is qualified and CPU WRITE clocks register **861**. AND gate **871** is disabled in the main routine. When ISR is high during interrupt, CPU WRITE clocks register **863** via qualified AND gate **871**, and AND gate **873** is disabled.

In FIG. **24**, two registers **881** and **883** both have D inputs connected to receive information simultaneously from the processor (e.g. ALU **21**). The registers are explicitly replicated in the diagram to illustrate the parallelism of this context switching construction so that, for example, ALU **21** feeds both D inputs of the registers **881** and **883**, wherein registers **881** and **883** illustratively act as accumulator ACC **23**. Correspondingly, multiplier **53**, for example, feeds the P register **51** including registers **891** and **893**. (Register **893** is not to be confused with BPR **185** of FIG.

A MUX **895** has its inputs connected respectively to the Q outputs of registers **881** and **883**. A MUX **897** has its inputs connected respectively to the Q outputs of registers **891** and **893**. The clock inputs of registers **881** and **891** are connected in parallel to an A output of an electronic reversing switch **901**. The clock inputs of register **883** and **893** are connected in parallel to a B output of reversing switch **901**. Interrupt hardware **903** responds to interrupt acknowledge IACK to produce a low active ISR- output when the interrupt service routine is in progress. Interrupt hardware **903** drives the toggle T input of a flip flop **905**. A Q output of flip flop **905** is connected both to a select input of switch **901** and to the select input of both MUmes **895** and **897** as well as MUXes for all of the strategic regisers.

A CPU WRITE line is connected to an X input of switch **901** and to an input of an AND gate **907**. The low active ISR- output of interrupt hardware **903** is connected to a second input of AND gate **907** the output of which is connected to a Y input of switch **901**.

In operation, a reset high initializes the set input of flip flop **905** pulling the Q output high and causing MUX **895** to select register **881**. Also, switch **901** is thereby caused to connect X to A and Y to B. In a main routine, ISR- is inactive high qualifying AND gate **907**. Accordingly, activity on the CFU WRITE line clocks all registers **881**, **883**, **891** and **893** in a main routine. This means that information from ALU **21** is clocked into both registers **881** and **883** at once and that information from multiplier **53** is clocked into both registers **891** and **893** at once, for example.

Then, upon a context change of which the interrupt service routine is an example, ISR- goes low and disables AND gate **907**. Subsequent CPU WRITE activity continues

to clock registers **881** and **891** for purposes of the interrupt routine, but fails to clock registers **883** and **893**, thus storing the contents of the main routine in these two latter registers by inaction. Therefore, a context switch occurs with no time overhead whatever. Upon a return to the original context, such as the main routine, ISR- once again goes high enabling AND gate **907**. The low to high transition toggles flip flop **905** causing MUXes **895** and **897** to change state and automatically select registers **883** and **893**. This again accomplishes an automatic zero-overhead context switch. Since flip flop **905** is toggled, switch **901** changes state to connect X to B and Y to A. Then activity on CPU write clocks both flip flops at once and registers **883** and **893** are active registers. A further interrupt (ISR- low) disables registers **881** and **891** while registers, **883** and **893** remain active. Thus, in FIG. **24** there is no main register or counterpart register, but instead the pairs of registers share these functions alternately.

In this way, FIG. **24** provides a switching circuit connecting the arithmetic logic circuit to both of two registers until an occurrence of the interrupt signal. The switching circuit temporarily disables one of the registers from storing further information from the arithmetic logic unit in response to the interrupt signal. Put another way, this context switching circuit like that of FIGS. **22** and **23** is operable to selectively clock first and second registers. Unlike the circuits of FIGS. **22** and **23**, the circuit of FIG. **24** has first and second registers, both having inputs connected to receive information simultaneously from the processor. The processor has a program counter as already discussed and is connected to these registers for executing a first routine and a second routine involving a program counter discontinuity.

In FIGS. **22–24**, a stack is, in effect, associated with a set of registers and the processor is operative upon a task change to the second routine for pushing the contents of the plurality of registers onto the stack. Similarly, upon return from interrupt, the processor pops the stack to allow substantially immediate resumption of the first routine. The second routine can be an interrupt service routine, a software trap, a subroutine, a procedure, a function or any other context changing routine.

In FIG. **25**, a method of operating the circuit of FIG. **24** initializes the Q output of flip flop **905** in a step **911**. Operations proceed in a step **913** to operate the output MUXes **895** and **897** based on the state of the Q output of flip flop **905**. Then a decision step **915** determines whether the context is to be switched in response to the ISR- signal, for example. If not, operations in a step **917** clock all registers **881**, **883**, **891** and **893** and loop back to step **913** whence operations continue indefinitely until in step **915** a context switch does occur. In such case, a branch goes from step **915** to a step **919** to clock only the registers selected by the MUXes (e.g. **895** and **897**). When return occurs, Q is toggled at flip flop **905** whence operations loop back to step **913** and continue indefinitely as described.

In FIG. **26**, device **11** is connected to an external ROM **951** and external RAM **953**, as well as an I/O peripheral **955** which communicates to device **11** at a ready RDY- input. Each of the peripheral devices **951**, **953** and **955** are connected by a peripheral data bus **957** to the data pins of device **11**. The memories **951** and **953** are both connected to a peripheral address bus **959** from device **11**. Enables are provided by lines designated IS-, PS- and DS- from device **11**. A WRITE enable line WE- is connected from device **11** to RAM **953** to support write operations.

As a practical matter, the processor in device **11** can run much faster than the peripherals and especially many low-cost memories that are presently available. Device **11** may be faster than any memories presently available on the market so when external memory is provided, wait states need to be inserted to give the memories and other peripherals time to respond to the processor. Software wait states can be added so that the device **11** automatically adds a software programmable number of wait states automatically. However, the different peripherals need fewer or larger numbers of wait states and to provide the same number of wait states for all peripherals is inefficient of processor time.

This problem is solved in the preferred embodiment of FIGS. **26** and **27** by providing software controlled wait state defined on memory page address ranges or boundaries and adaptively optimized for available memories and peripheral interfaces. This important configuration eliminates any need for high speed external glue logic to decode addresses and generate hardware wait states.

In contrast with the glue logic and hardware wait state approach, the programmable page boundary oriented solution described herein requires no external glue logic which would otherwise need to operate very fast and thus require fastest, highest power and most expensive logic to implement the glue function. Elimination of glue logic also saves printed circuit board real estate. Furthermore, the processor can then be operated faster than any available glue logic.

The preferred embodiment thus combines with a concept of software wait states, the mapping of the software wait states on memory pages. The memory pages are defined as the most common memory block size used in the particular processor applications, for example. The number of wait states used for a specific block of memory is defined in a programmable register and can be redefined. The wait state generator generates the appropriate number of wait states as defined in the programmable register any time an address is generated in the respective address range or page or blocks. The mapping to specific bank sizes or page sizes eliminates any need for external address decoded glue logic for accelerating external cycles. External peripheral interfaces are decoded on individual address locations and the software wait state generator not only controls the number of wait states required for each individual peripheral, but is also compatible with ready line control for extending the number of wait states beyond the programmed amount.

A programmable wait state circuit of FIG. **27** causes external accesses to operate illustratively with 0 to 15 wait states extendable by the condition of a ready line RDY-. Wait states are additional machine cycles added to a memory access to give additional access time for slower external memories or peripherals. It at the completion of the programmed number of wait states the ready line is low, additional wait states are added as controlled by the ready line. The wait state circuit of FIG. **27** includes a 4-bit down register block **971** connected to a WAIT- input of the processor in device **11** of FIG. **21** by an OR gate **974**. Gate **974** has low-active inputs as well as output. The ready line RDY- is connected to an input of OR- gate **974**. A set of registers **975** has illustratively sixteen locations of four bits each. Each of the four bit nibbles defines a number of wait states from 0 to 15 on Q output lines to wait state generator **971**. When device **11** asserts an address to one of the peripherals **951**, **953** or **955** on a peripheral address bus **959**, an on-chip decoder **977** decodes the most significant bits MSB representing the page of memory which is being addressed. For example, in the system of FIG. **26** there are **16** pages of memory. Decoder **977** selects one of the **16** four bit nibbles in the registers **975** and outputs the selected nibble to wait state generator **971**. Generator **971** corre-

spondingly counts down to zero and thereby produces the wait states defined by the nibble. The registers **975** are loaded via data bus **111**D initially in setting up the system based on the characteristics of the peripherals. Thus in the preliminary phase, the data address bus **111**A asserts an address to decoder **977** and a select line SEL is activated. Decoder **977** responds to the address on bus **111**A to select one of the registers **975** into which is written the programmed number of wait states via data bus **111**D. Thus, the number of wait states defined for a specific address segment or page is defined by the wait state control registers PWSR**0**, PWSR**1**, DWSR**0**, DWSR**1**, IWSR**0**, IWSR**1**, IWSR**2** and IWSR**3**. Decoder **977** is itself suitably further made programmable by data buses **111**A and **111**D by providing one or more registers to define programmable widths of address ranges to which the decoder **977** is to be responsive.

More specifically, with reference to the software wait state generator, the program space is illustratively broken into 8K word segments. For each 8K word segment is programmed a corresponding four bit value in one of the PWSR registers to define 0 to 15 wait states. The data space is also mapped on 8K word boundaries to the two DWSR registers.

The wait state control registers **975** are mapped in the address space. On-chip memory and memory mapped registers in the CPU core **13**, **15** are not affected by the software wait state generators. on-chip memory accesses operate at full speed. Each wait state adds a single machine cycle.

The PWSR registers are provided for program memory wait states. The DWSR registers are provided for data memory wait states. The IWSR registers are provided for I/O peripheral wait states.

Since the wait states are software programmable, the processor can adapt to the peripherals with which it is used. Thus, the wait state values in registers **975** can be set to the maximum upon startup and then the amount of time that is required to receive a ready signal via line **978** is processed by software in order to speed up the processor to the maximum that the peripherals can support. Some of the I/O may be analog-to-digital converters. Memories typically come in blocks of 8K. Each of the peripherals has its own speed and the preferred embodiment thus adaptively provides its own desirable set of wait states. Larger size memories can be accommodated by simply putting the same wait state value in more than one nibble of the registers **975**. For example, device **11** can interact with one block of memory which can be a low speed EPROM that is 8K wide which is used together with a high speed block of RAM that is also 8K. As soon as the CPU addresses the EPROM, it provides a greater number of wait states. As soon as the CPU addresses the high speed RAM, it uses a lesser amount of wait states. In this way, no decode logic or ready logic off-chip is needed to either slow down or speed up the device appropriately for different memories. In this way, the preferred embodiment affords a complete control when used with a user's configuration of a off-chip memory or other peripheral chips.

Upon system reset, in some embodiments it is advisable to set the registers with a maximum value of 15 wait states so that the device **11** runs relatively slowly initially and then have software speed it up to the appropriate level rather than having device **11** run very fast initially which means that it will be unable to communicate effectively with the peripherals in the initial phase of its operations.

In this way, device **11** is readily usable with peripheral devices having differing communication response periods. CPU core **13**, **15** acts as a digital processor adapted for selecting different ones of the peripheral devices by asserting addresses of each selected peripheral device. Registers **975** are an example of addressable programmable registers for holding wait state values representative of distinct numbers of wait states corresponding to different address ranges. Decoder **977** and wait state generator **973** act as circuitry responsive to an asserted address to the peripheral devices asserted by the digital processor for generating the number of wait states represented by the value held in one of the addressable programmable registers corresponding to one of the address ranges in which the asserted address occurs. In this way, the differing communication response periods of the peripheral devices are accommodated.

Decoder **977** responds to the CPU core for individually selecting and loading the wait state generator with respective values representing the number of wait states to be generated. In other embodiments, individual programmable counters for the pages are employed.

FIG. **28** is a process diagram for describing the operation of two instructions CRGT and CRLT. These two instructions involve a high speed greater-than and less-than computation which readily computes maximums and minimums when used repeatedly. Operations commence with a start **981** and proceed to determine whether the CRGT or CRLT instruction is present. When this is the case, operations go on to a step **985** to store the ALU **21** to accumulator **23** in FIG. **1**A. Then in a step **987**, the ALU selects the contents of ACCB **31** via MUX **77** of FIG. **1**A. In a step **989**, the ALU is coactively operated to compare the contents of accumulator **23** to ACCB **31**, by subtraction to obtain the sign of the arithmetic difference, for instance. In step **991**, the greater or lesser value depending on the instruction CRGT or CRLT respectively is supplied to ACCB **31** by either storing ACC **23** to ACCB **31** or omitting to do so, depending on the state of the comparison. For example, if ACC **23** has a greater value then ACCB **31** and the instruction is CRGT, then the ACC is stored to ACCB, otherwise not. If ACC **23** has a lesser value then ACCB and the instruction is CRLT, then the ACC is stored to ACCB. In some embodiments, when ACCB already holds the desired value, a transfer writes ACCB into ACC. Subsequently, a test **993** determines whether a series of values is complete. If not, then operations loop back to step **983**. If the series is complete in step **993**, operations branch to a step **995** to store the maximum or minimum value of the series which has been thus computed.

The capacity to speedily compute the maximum of a series of numbers is particularly beneficial in an automatic gain control system in which a multiplier or gain factor is based on a maximum value in order to raise or lower the gain of an input signal so that it can be more effectively processed. Such automatic gain control is used in radio receivers, audio amplifiers, modems and also in control systems utilizing algorithms such as the PID algorithm. PID is a proportional integral and differential feedback control system. Still another application is in pattern recognition. For example, in a voice or recognition system, solid hits of recognition by comparison of pre-stored voice patterns to incoming data are determined by looking at a maximum in a template comparison process. Also, in image processing, edge detection by a processor analyzes intensities in brightness and in color. When intensities rise and then suddenly fall, a maximum is detected which indicates an edge for purposes of image processing.

In this way, an arithmetic logic unit, an instruction decoder, an accumulator and an additional register are combined. The additional register is connected to the arithmetic logic unit so that the arithmetic logic unit supplies a first arithmetic value to the accumulator and then supplies to

the register in response to a command from the instruction decoder the lesser or greater in value of the contents of the additional register and the contents of the accumulator. Repeated execution of the command upon each of a series of arithmetic values supplied over time to the accumulator supplies the register with a minimum or maximum value in the series of arithmetic values.

It is critically important in many real time systems to find a maximum or minimum with as little machine cycle overhead as possible. The problem is compounded when temporary results of the algorithm are stored in accumulators that have more bits than the word width of a data memory location where the current minimum or maximum might be stored. It is also compounded by highly pipelined processors when condition testing requires a branch. Both cases use extra machine cycles. Additional machine cycles may be consumed in setting up the addresses on data transfer operations.

In the preferred embodiment, however, the circuit has ACCB **31** be a parallel register of the same bit width as the accumulator ACC **23**. When the minimum or maximum function is executed, the processor compares the latest values in the accumulator with the value in the parallel register ACCB and if less than the minimum or greater than the maximum, depending on the instruction, it writes the accumulator value into the parallel register or vice versa. This all executes with a single instruction word in a single machine cycle, thus saving both code space and program execution time. It also requires no memory addressing operations and it does not affect other registers in the ALU.

FIG. **29** illustrates a pipeline organization of operational steps of the processor core **13**, **15** of device **11**. The steps include fetch, decode, read and execute, which for subsequent instructions are staggered relative to a first instruction. Thus, when the pipeline is full, one instruction is being executed simultaneously with a second instruction being read, a third instruction being decoded and a fourth instruction in the initial phase of fetch. This prefetch, decode, operand-fetch, execute pipeline is invisible to the user. In the operation of the pipeline, the prefetch, decode, operand-fetch, and execute operations are independent, which allows instructions to overlap. Thus during any given cycle, four different instructions can be active, each at a different stage of completion. Each pipeline break (e.g., branch, call or-return) requires a 2 to 3 cycle pipeline loading sequence as indicated by cycles **1**, **2**, and **3** of FIG. **29**. To improve the code efficiency when a program requires a high number of branches or other discontinuities in the program addressing, the instruction set includes certain additional instructions.

For example, a delayed branch when executed completes the execution of the next two instructions. Therefore, the pipeline is not flushed. This allows an algorithm to execute a branch in two cycles instead of four and the code lends itself to delayed branches. A status condition for a branch is determined by instructions previous to a delayed branch. Instructions placed after the branch do not affect the status of the branch. This technique also applies to subroutine calls and returns. The delayed branch instructions also support the modification of auxiliary registers.

Pipeline operation is protected against interrupt such that all non-recoverable operations are completed before interrupt is taken.

To further improve the performance of the pipeline, the processor handles two kinds of conditional instructions. Conditional subroutine calls and returns help in error and special condition handling. If a condition is true, the call or return is executed. The format for conditional call and return pneumonic are Cxxxx where xxxx is the condition code; CGEZD: call greater than or equal delay; Rxxxx where xxxx is the condition code; and RIOZ: return on BIO PIN LOW.

Conditional instructions advantageously improve coding of high sampling frequency algorithms, for example. They allow conditional execution of the next one or the next two following instructions with a very low cycle overhead. The test conditions are the same as for branch instructions. The first instruction following a conditional instruction does not modify auxiliary registers and does not reload the program counter **93**. These restrictions do not apply for the second conditional instruction. The format for the conditional instruction mnemonic is CExxxx where xxxx is the condition code, and CEGEZ: execute next instruction(s) if greater than equal. If the test is true, the next instructions) are executed. If the condition is false, each conditioned instruction is replaced by a NOP.

The following code shows an example of conditioning instruction use: SUBB Y0; CEGEZ **2**; SUBB X0; SACL*+If the test condition is true the two instructions SUBB and SACL are executed. If not, they are replaced by a NOP.

When the pipeline is full and continually being fed with instructions, it is as shown in columns **4** and **5** of FIG. **29**, filled with four instructions continually. In FIG. **30**, the fully loaded column is shown laid over horizontal with instructions A, B, C and D therein. When a conditional instruction Ccnd is in the pipeline and the condition is not met, only one cycle is lost. However, as shown in the lower part of FIG. **30**, a conventional instruction causes a branch and requires reloading of the pipeline as in cycle **1** and thus require four cycles to reload the pipeline. This is called a pipeline hit. Consequently, as FIG. **30** illustrates, the conditional instruction affords a savings of three cycles of processor time.

Arithmetic operations benefit by introducing conditional instructions. For example, if a positive number X is multiplied by a negative number Y, the desired answer is a negative number Z. To obtain this result, the operations conventionally might include determining the absolute value of −Y to recover Y and then multiplying by X to determine Z and then negating Z to obtain −Z. Determining whether or not the number is negative involves a sign condition which can cause a pipeline hit. A second example is in execution of double precision addition or subtraction. If a double precision number (W,X) is to be added to a double precision number (Y,Z) the first step would be to add W+Y and then X+Z. However, if the condition is true that there is a carry resulting from the addition X+Z, then the sum W+Y should be modified to be W+Y+C (carry). The computation unit **15** thus acts as a circuit having status conditions wherein a particular set of the status conditions can occur in operation of the circuit. Some status conditions, for example, are Z) accumulator equal to 0, L) accumulator less than 0, V) overflow and C) carry.

The instruction register IR of FIGS. **1**A and **31** is operative to hold a conditional instruction directing control circuit **225** to execute a further operation provided that the particular status condition is present. Line **1026** carries signals indicative of the actual status of accumulator **23** back to decoder **221** or control **225**. The decoder decodes the instruction register and control circuit **225** is connected to the processor to cause it to execute a further operation when a particular status condition is present and otherwise to cause the circuit to omit the further operation. In this way, a branch is avoided and no pipeline hit occurs.

The instruction register also includes sets of bits **1021** and **1023** interpreted as status and mask bits of FIG. **32** when a conditional instruction is present in the I.R. In other words,

decoder **221** is enabled by the presence of a conditional instruction to decode the predetermined bit locations **1021** as status bits and the predetermined bit locations **1023** as mask bits. Decoder **221** decodes the predetermined mask location corresponding to the status conditions to selectively respond to the certain ones of the predetermined status conditions when the conditional instruction is present in the instruction register. In this way, the processor is able to perform high sample rate algorithms in a system that has an analog-to-digital converter A/D **1003** converting the output of a sensor **1005** for the processor. The processor executes high precision arithmetic and supplies the results to a video output circuit **1007** that drives a CRT **1009**.

In FIG. **32**, the mask bits **1023** predetermine the accumulator status to which the conditional instruction is responsive. The status bits **1021** predetermine the way in which the condition is interpreted. Note that status bits **1021** are not sensed bits from line **1026**. For example, mask bits **1023** are "1101", meaning that accumulator overflow status is ignored and all other statuses are selected. Status bits **1021** are "1001", meaning that the actual accumulator condition is compared to ACC-0 AND NOT (ACC<0) and CARRY. In other words, the zero (0) in the ACC<0 bit L of FIG. **32** sensitizes the circuitry to the logical complement NOT ACC<0 (or ACC greater than zero)e If this threefold condition is met, the conditional instruction is operative in this example.

In a further advantage of the use of these remarkable conditional instructions, FIG. **33** shows that implementing many short instructions without the status or mask bits **1021** and **1023** results in a larger decoder being required to decode the numerous different instructions. However, in FIG. **34** with one longer conditional instruction (illustrated as a conditional branch instruction), the use of status and mask bits results in a smaller decoder **1025** than would otherwise be required. This hardware gives the status and mask option to the assembler which has the capability of doing large numbers of options and generates the correct bit pattern that would have to be done in decoder PLA on a conventional processor. In this way, the decode period is shortened and there are fewer transistors in the decode systems. Decode of the branch instruction is sped up, fewer transistors are required for the implementation and there is greater flexibility.

In the conditional branch instruction feature, a branch is sometimes required. However, pipeline hits are minimized by conjoining various status conditions as in FIG. **32**. For example, in extended precision arithmetic, in doing an add, it may be necessary to look at the carry bit if there is a positive value, but there is no need to do an operation based on there being a negative value. Therefore, the conditional branch instruction senses the simultaneous presence of both carry and positive conditions as shown in FIG. **32**.

In FIG. **34**, an operation circuit such as computation unit **15** of FIGS. **1**A and **34** acts as a circuit that has status conditions wherein a particular set of status conditions can occur in operation of the circuit. Instruction register IR holds a conditional branch instruction that is conditional on a particular set of the status conditions. The decoder **1025** is connected to instruction register IR and operation circuit **15**. Then the program counter **93** is coupled to decoder **1025** via a MUX **1027** so that a branch address ADR is entered into the program counter **93** in response to the branch instruction when the particular set of the status conditions of the circuit **15** are present. Otherwise, MUX **1027** selects clock pulses which merely increment the program counter. In many cases, not all of the status conditions will be actually occurring in circuit **15** and no branch occurs, thus avoiding a pipeline hit. The program counter **93** contents are used to address the program memory **61** which then enters a subsequent instruction into the instruction register IR.

The conditional instructions are advantageously utilized in any application where there is insufficient resolution in the word length of the processor in the system and it is desired to use double or higher multiple precision. For example, audio operations often require more than 16 bits. In a-control algorithm, some part of the control algorithm may require more than 16 bits of accuracy.

FIG. **35** shows a specific example of logic for implementing the status and mask bits **1021** and **1023** of FIGS. **31**, **32** and **34**. In FIG. **35**, the actual status of operation circuit **15** ((ACC=0), (ACC<Q), overflow, (CARRY)) is compared in exclusive OR gates **1031.1**, **1031.2**, **1031.3** and **1031.4** with the status bits Z, L, V and C of the status register **1021**. If the status is actually occurring, then the respective XOR gate supplies as active low to its corresponding AND gate **1033.1**, **1033.2**, **1033.3** or **1033.4**. An additional input of each of the AND gates **1033** is qualified or disabled by with a corresponding high active mask bit Z, L, V or C. In this way, only the appropriate conditions are selectively applied to a logic circuit **1035** which selects for the appropriate conjunctions of conditions to which the conditional set is sensitive. If the conjunction of conditions is present, then a branch output of logic **1035** is activated to the control circuit **225** of FIG. **34**.

FIG. **36** shows a pin-out or bond-out option for device **11**. In FIG. **36**, device **11** is terminated in an **84** pin CERQUAD package. The pin fuctions are described in a SIGNAL DESCRIPTIONS appendix. hereinbelow. Advantageously, the arrangement of terminals and design of this pin-out concept prevents damage to device **11** even when the chip is mistakenly misoriented in a socketing process.

As shown in FIG. **37**, the chip package can be oriented in any one of four directions **1041**A, **1041**B, **1041**C and **1041**D. Device **11** is an example of an electronic circuit having a location for application of power supply voltage at seven terminals $V_{cc1\text{-}7}$. There are also seven ground pins $V_{ss1\text{-}7}$. The numerous leads are used to apply power to different areas of device **11** to isolate inputs and internal logic from output drivers which are more likely to produce noise. Especially on very high speed processors, substantial currents can be drawn which causes voltages on the printed circuit ground plane. The buses that switch hard and fast are thus isolated from buses that are not switching. Address and data are isolated from control lines so that when they switch hard and fast wherein all the addresses switch at the same time, it will not affect the other bus because the ground is isolated. Likewise, other output pins that are not memory oriented or have to be stable at the times that addressing is occurring are also not affected because of the isolation. Therefore, the isolation of the ground and power plans is optimized so that hard switching devices do not cause noise on pins that are not switching at that time and need to be stable in voltage.

The exemplary embodiment of FIG. **36** is an 84 pin J-leaded device wherein the terminals comprise contact surfaces adapted for surface mounting. The terminals are physically symmetric with quadrilateral symmetry.

In FIGS. **36** and **37**, the symmetrical placement of the power and ground pins is such that any of the four orientations of the device causes the power and ground pins to plug into other power and ground pins respectively. In a further advantageous feature, a disabling terminal designated as the OFF- pin is provided so that any placement of

the device **11** other than the correct orientation automatically aligns this low active OFF- pin to a ground connection on printed circuit board **1043**. When the OFF- pin is driven low, then all outputs of device **11** are tristated so that none of the outputs can be driving against anything else in the system. In this way, device **11** responds to application of the ground voltage to the disabling terminal for non-destructively disabling the electronic circuitry of the device **11**.

Put another way, the chip carrier of FIG. **36** is an example of a keyless device package for holding the electronic circuit and includes terminals secured to the device package for the supply voltage output locations and disable terminal wherein every turning reorientation of the entire electronic device which translates the terminals to each other translates a terminal for supply voltage to another terminal for supply voltage. Likewise, terminals for ground are either translated to other terminals for ground or to the terminal for disablement. In some embodiments, it may be desirable to make the disable terminal high active and in those embodiments, the disabled terminal is translated to a supply voltage terminal for this disabling purpose.

The range of applications of this pin-out concept is extremely broad. The device **11** can be any electronic device such as a digital signal processor, a graphic signal processor, a microprocessor, a memory circuit, an analog linear circuit, an oscillator, a resistor pack, or any other electrical circuit. The device package suitably is provided as a surface mount package or a package with pins according to the single-in-line design or dual in-line design. The protective terminal arrangement improvement applies to cable interconnects, a printed circuit board connecting to a back plane or any electrical component interconnection with symmetrical connection.

In FIG. **38**, an automatic chip socketing machine **1051** is provided with PC boards **1043** and devices **11** for manufacturing assembly of final systems. If the devices **11** are mistakenly misoriented in the loading of socketing machine **1051**, there is no damage to the chip upon reaching test apparatus **1053** even though the chip orientation is completely incorrect in its placement on the board **1043**.

It would be undesirable for misorientation of the device to allow voltages to be applied in test area **1053** which execute a strain on the output drivers of the device as well as possibly straining some of the circuits of other chips on the printed circuit board **1043**. Such strain might result in shorter lifetimes and a not insignificant reliability issue for the system. Advantageously, as indicated in the process diagram of FIG. **39**, this reliability issue is obviated according to the pin-out of the preferred embodiment of FIG. **36**.

In this processing method, operations commence with a START **1061** and proceed to a step **1063** to load the circuit boards **1043** into machine **1051**. Then, in a step **1065**, keyless devices **11** are loaded into machine **1051**. Next, in a step **1067**, machine **1051** is operated and the devices are socketed in a step **1069**. Subsequently, in test area **1053**, the board assemblies are energized in step **1071** of FIG. **39**. Test equipment determines whether the assemblies are disabled in their operation. This step is process step **1073**. If not, then a step **1075** passes on the circuit assemblies which have been electrically ascertained to be free of disablement to further manufacturing or packaging steps since these circuit assemblies have proper orientation of the keyless electronic devices.

If any of the circuit boards **1043** has misoriented devices, then test equipment **1053** determines which circuit assemblies are disabled in step **1073** of FIG. **39** and operations proceed to a step **1077** to reorient the devices **11** on the printed circuit boards **1043** and to reload the keyless devices starting with step **1065**. Operations then pass from both steps **1075** and **1077** to step **1063** for re-execution of the process.

In FIG. **40**, another preferred embodiment of the pin-out feature is implemented in a single in-line chip wherein multiple power terminals VCC and ground are provided. In this way, if the chip is reversed, the power pins and ground pins are still lined up. An OFF- pin translates to a ground pin on the symmetrically opposite side of this single in-line package.

In FIG. **41**, the single in-line concept has an odd number of pins with the power pin VCC supplied to the center of symmetry. A ground pin is at a symmetrically opposite end of the chip from the disabling terminal OFF-. Then, when the chip is tested after assembly and the system is not working, the manufacturer can reorient the chip and not have to be concerned about possibly having damaged the chip or the printed circuit assembly into which it has been introduced.

FIG. **42** shows a sketch of terminals on a dual in-line package. Crossed arrows illustrate the translation concept of the reorientation. It is to be understood of course that reorientation does not connect terminals to terminals. Reorientation instead connects terminals on the chip, which have one purpose, to corresponding contacts on the board that have the purpose for which a symmetrically opposing pin on the chip is intended. In this way, the concept of translation of terminals to terminals is effective to analyze the advantages of the preferred embodiments of this pin-out improvement.

As indicated in the sketch of FIG. **43**, the further embodiments of the pin-out improvement are applicable to pin grid array (PGA) terminal and package configurations.

In still other embodiments wherein the terminals have four possible orientations, the terminals suitably include at least one power terminal, an odd number of ground terminals, and at least one disable terminal or a whole number multiple.

In still other embodiments, the terminals include ground and disable terminals and have a number of possible orientations wherein the sum of the number of ground terminals and the number of disable terminals is equal to or is a whole number multiple of the number of possible orientations.

Structurally on chip, the preferred embodiment as thus far described has the disabling circuitry to force all the pins to float. In still other embodiments, all output pins translate to other output pins. All VCC pins translate to other VCC pins and all ground pins translate to other ground pins. Any pin can translate to a no-connect pin.

Where all-hardware embodiments have been shown herein, it should be understood that other embodiments of the invention can employ software or microcoded firmware. The process diagrams herein are also representative of flow diagrams for software-based embodiments. Thus, the invention is practical across a spectrum of software, firmware and hardware.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to this description. It is therefore contemplated that the appended claims will cover any such modifications or embodiments as fall within the true scope of the invention.

INSTRUCTION	NEU	OPCODE				IMMEDIATE			
LOAD AR FROM ADDRESSED DATA	LAR	0000	0ARX	IAAA	AAAA				
ADD TO AR SHORT IMMEDIATE	ADRK	0000	1000	IIII	IIII				
SUBTRACT FROM AR SHORT IMMEDIATE	SBRK	0000	1001	IIII	IIII				
MODIFY AUXILIARY REGISTER	MAR	0000	1010	IAAA	AAAA				
EXCLUSIVE OR OBMR TO DATA VALUE	XPL	0000	1011	IAAA	AAAA				
OR DBMR TO DATA VALUE	OPL	0000	1100	IAAA	AAAA				
AND DBMR WITH DATA VALUE	APL	0000	1101	IAAA	AAAA				
COMPARE DBMR TO DATA VALUE	CPL	0000	1111	IAAA	AAAA				
TEST BIT SPECIFIED IMMEDIATE	BIT	0001	B1TX	IAAA	AAAA				
LOAD ACCUMULATOR WITH SHIFT	LAC	0010	SHFT	IAAA	AAAA				
ADD TO ACCUMULATOR WITH SHIFT	ADD	0011	SHFT	IAAA	AAAA				
SUBTRACT FROM ACCUMULATOR WITH SHIFT	SUB	0100	SHFT	IAAA	AAAA				
ZERO ACC. LOAD HIGH ACC WITH ROUNDING	ZALR	0101	0000	IAAA	AAAA				
ZERO ACC. LOAD HIGH ACCUMULATOR	ZALM	0101	0001	IAAA	AAAA				
ZERO ACC. LOAD LOW ACC WITH SIGN SUPPRESSED	ZALS	0101	0010	IAAA	AAAA				
LOAD ACC WITH SHIFT SPECIFIED BY TREG1	LACT	0101	0011	IAAA	AAAA				
MULTIPLY DATA VALUE TIMES TREG0	NPY	0101	0100	IAAA	AAAA				
MULTIPLY UNSIGNED DATA VALUE TIMES TREG0	NPYU	0101	0101	IAAA	AAAA				
TEST BIT IN DATA VALUE AS SPECIFIED BY TREG2	BITT	0101	0110	IAAA	AAAA				
NORMALIZE ACCUMULATOR	NORM	0101	0111	IAAA	AAAA				
LOAD STATUS	LST	0101	1000	IAAA	AAAA				
LOAD STATUS REGISTER 1	LST1	0101	1001	IAAA	AAAA				
MUBL/ACC WITH SOURCE ADDRESS IN OBMR	NADS	0101	1010	IAAA	AAAA				
MULT/ACC WITH SOURCE ADRS IN DBMR AND OBOV	NADO	0101	1011	IAAA	AAAA				
BLOCK MOVE DATA TO DATA WITH SOURCE IN DBMR	BOSD	1010	1100	IAAA	AAAA				
BLOCK MOVE DATA TO DATA WITH DEST IN DBMR	BODO	0101	1101	IAAA	AAAA				
BLOCK MOVE DATA TO PROG WITH SOURCE IN DBMR	BPSD	0101	1110	IAAA	AAAA				
BLOCK MOVE DATA TO DATA DEST LONG IMMEDIATE	BKDK	0101	1111	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
ADD TO ACCUMULATOR WITH CARRY	ADDC	0110	0000	1AA	AAAA				
ADD TO HIGH ACCUMULATOR	ADDH	0110	0001	IAAA	AAAA				
ADD TO LOW ACCUMULATOR WITH SIGN SUPPRESSED	ADDS	0110	0010	IAAA	AAAA				
ADD TO ACC WITH SHIFT SPECIFIED BY TREG1	ADDT	0110	0011	IAAA	AAAA				
MULTIPLY TREG0 BY DATA, ADD PREVIOUS PRODUCT	NPYA	0110	0100	IAAA	AAAA				
DATA TO TREG0, SQUARE IT, ADD PREG TO ACC	SQRA	0110	0101	IAAA	AAAA				
LOAD TREG0 AND ACCUMULATE PREVIOUS PRODUCT	LTA	0110	0110	IAAA	AAAA				
LOAD TREG0 WITH DATA SHFT, ADD PREG TO ACC	LTD	0110	0110	IAAA	AAAA				
LOAD TREG0	LT	0110	1000	IAAA	AAAA				
LOAD TREG0 AND LOAD ACC WITH PREG	LTP	0110	1001	IAAA	AAAA				
EXCLUSIVE OR ACCUMULATOR WITH DATA VALUE	XDR	0110	1010	IAAA	AAAA				
OR ACCUMULATOR WITH DATA VALUE	OR	0110	1011	IAAA	AAAA				
AND ACCUMULATOR WITH DATA VALUE	AND	0110	1100	IAAA	AAAA				
TABLE WRITE	TBLW	0110	1101	IAAA	AAAA				
RESERVED									
RESERVED									
SUBTRACT FROM ACCUMULATOR WITH BORROW	SUBB	0111	0000	IAAA	AAAA				
SUBTRACT FROM HIGH ACCUMULATOR	SUBM	0111	0001	IAAA	AAAA				
SUBTRACT FROM ACC WITH SIGN SUPRESSED	SUBS	0111	0010	IAAA	AAAA				
SUBTRACT FROM ACC, SHIFT SPECIFIED BY TREG1	SUBT	0111	0011	IAAA	AAAA				
MULTIPLY TREG0 BY DATA, ACC-PREG	NPYS	0111	0100	IAAA	AAAA				
DATA TO TREG0, SQUARE IT, ACC-PREG	SQRS	0111	0101	IAAA	AAAA				
LOAD TREG0 AND SUBTRACT PREVIOUS PRODUCT	LTS	0111	0110	IAAA	AAAA				

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CONDITIONAL SUBTRACT	SUBC	0111	0111	IAAA	AAAA				
REPEAT INSTRUCTION AD SPECIFIED BY DATA	PRT	0111	1000	IAAA	AAAA				
LOAD DATA PAGE POINTER WITH ADDRESSED DATA	LDP	0111	1001	IAAA	AAAA				
PUSH DATA MEMORY VALUE ONTO PC STACK	PSHD	0111	1010	IAAA	AAAA				
DATA MOVE IN DATA MEMORY	DMOV	0111	1011	IAAA	AAAA				
LOAD HIGH PRODUCT REGISTER	LPH	0111	1100	IAAA	AAAA				
RESERVED									
RESERVED									
RESERVED									
STORE LOW ACCUMULATOR WITH SHIFT	SACL	1000	0SHF	IAAA	AAAA				
STORE HIGH ACCUMULATOR WITH SHIFT	SACH	1000	1AHF	IAAA	AAAA				
STORE AR TO ADDRESSED DATA	SAR	1001	0ARX	IAAA	AAAA				
STORE STATUS	SST	1001	1000	IAAA	AAAA				
STORE STATUS REGISTER 1	SST1	1001	1001	IAAA	AAAA				
TABLE READ	TBLR	1001	1010	IAAA	AAAA				
STORE LOW PRODUCT REGISTER	SPL	1001	1011	IAAA	AAAA				
STORE HIGH PRODUCT REGISTER	SPH	1001	1100	IAAA	AAAA				
POP STACK TO DATA MEMORY	POPD	1001	1101	IAAA	AAAA				
BLOCK MOVE PROG TO DATA WITH SOURCE IN DBMR	BPDS	1011	1110	IAAA	AAAA				
BLOCK MOVE FROM PROGRAM TO DATA MEMORY	BLKP	1001	1111	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
MULTIPLY/ACCUMULATE	MAC	1010	0000	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
MULTIPLY/ACCUMULATE WITH DATA SHIFT	MACD	1010	0001	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
BRANCH UNCONDITIONAL WITH AR UPDATE	B	1010	0010	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
CALL UNCONDITIONAL WITH AR UPDATE	CALL	1010	0011	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
BRANCH AR = 0 WITH AR UPDATE	BANZ	1010	0100	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
BRANCH UNCONDITIONAL WITH AR UPDATE DELAYED	BD	1010	0101	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
CALL UNCONDITIONAL WITH AR UPDATE DELAYED	CALD	1010	0110	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
BRANCH AR = 0 WITH AR UPDATE DELAYED	BAZD	1010	0111	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
LOAD MEMORY MAPPED REGISTER	LMMR	1010	1000	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
STORE MEMORY MAPPED REGISTER	SMMR	1010	1001	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
BLOCK MOVE FROM DATA TO DATA MEMORY	BLKD	1010	1010	IAAA	AAAA	AAAA	AAAA	AAAA	AAAA
STORE LONG IMMEDIATE TO DATA	SPLK	1010	1011	IAAA	AAAA	IIII	IIII	IIII	IIII
EXCLUSIVE OR LONG IMMEDIATE WITH DATA VALUE	XPLK	1010	1100	IAAA	AAAA	IIII	IIII	IIII	IIII
OR LONG IMMEIDIATE WITH DATA VALUE	OPLK	1010	1101	IAAA	AAAA	IIII	IIII	IIII	IIII
AND LONG IMMEDIATE WITH DATA VALUE	APLK	1010	1110	IAAA	AAAA	IIII	IIII	IIII	IIII
COMPARE DATA WITH LONG IMMEDIATE SET TC IF =	CPLK	1010	1111	IAAA	AAAA	IIII	IIII	IIII	IIII
LOAD AR SHORT IMMEDIATE	LARK	1011	0ARX	IIII	IIII				
ADD TO LOW ACC SHORT IMMEDIATE	ADDK	1011	1000	IIII	IIII				
LOAD ACC SHORT IMMEDIATE	LACK	1011	1001	IIII	IIII				
SUBTRACT FROM ACC SHORT IMMDIATE	BUSK	1011	1010	IIII	IIII				
REPEAT INST SPECIFIED BY SHORT IMMEDIATE	RPTX	1011	1011	IIII	IIII				
LOAD DATA PAGE IMMEDIATE SHORT IMMEDIATES	LDPX	1011	1101	IIII	IIII				
ABSOLUTE VALUE OF ACCUMULATOR	ABS	1011	1110	0000	0000				
COMPLEMENT ACCUMULATOR	CMPL	1011	1110	0000	0001				
NEGATE ACCUMULATOR	NEG	1011	1110	0000	0010				
LOAD ACCUMULATOR WITH PRODUCT	PAC	1011	1110	0000	0011				
ADD PRODUCT TO ACCUMULATOR	APAC	1011	1110	0000	0100				
SUBTRACT PRODUCT FROM ACCUMULATOR	SPAC	1011	1110	0000	0101				
ADD BPR TO ACCUMULATOR	ABPR	1011	1110	0000	0110				
LOAD ACCUMULATOR WITH BPR	LBPR	1011	1110	0000	0111				
SUBTRACT BPR FROM ACCUMULATOR	SBPR	1011	1110	0000	1000				
SHIFT ACCUMULATOR 1 BIT LEFT	SFL	1011	11110	0000	1001				
SHIFT ACCUMULATOR 1 BIT RIGHT	SFR	1011	1110	0000	1010				
ROTATE ACCUMULATOR 1 BIT LEFT	ROL	1011	1110	0000	1100				
ROTATE ACCUMULATOR 1 BIT RIGHT	ROR	1011	1110	0000	1101				
ADD ACCB TO ACCUMULATOR	ADDR	1011	1110	0001	0000				
ADD ACCB TO ACCUMULATOR	ADCR	1011	1110	0001	0001				

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WITH CARRY									
ADD ACCB WITH ACCUMULATOR ANDR	1011	1110	0001	0010					
OR ACCB WITH ACCUMULATOR	ORR	1011	1110	0001	0011				
ROTATE ACCB AND ACCUMULATOR LEFT	RDLR	1011	1110	0001	0100				
ROTATE ACCB AND ACCUMULATOR RIGHT	RDRR	1011	1110	0001	0101				
SHIFT ACCB AND ACCUMULATOR LEFT	SFLR	1011	1110	0001	0110				
SHIFT ACCB AND ACCUMULATOR RIGHT	SFRR	1011	1110	0001	0111				
SUBTRACT ACCB FROM ACCUMULATOR	SUBR	1011	1110	0001	1000				
SUBTRACT ACCB FROM ACCUMULATOR WITH CARRY	SBBR	1011	1110	0001	1001				
EXCLUSIVE OR ACCB WITH ACCUMULATOR	XORR	1011	1110	0001	1010				
STROE ACC IN ACCB IF ACC > ACCR	CRGT	1011	1110	0001	1011				
STORE ACC IN ACCB IF ACC < ACCR	CRLT	1011	1110	0001	1100				
EXCHANGE ACCR WITH ACCUMULATOR	EXAR	1011	1110	0001	1101				
STORE ACCUMULATOR IN ACCB	SACR	1011	1110	0001	1110				
LOAD ACCUMULATOR WITH ACCB	LACR	1011	1110	0001	1111				
BRANCH ADDRESSED BY ACC	BACC	1011	1110	0010	0000				
BRANCH ADDRESSED BY ACC DELATED	BACD	1011	1110	0010	0001				
IDLE	IDLE	1011	1110	0010	0010				
PUSH LOW ACCUMULATOR TO PC STACK	PUSH	1011	1110	0011	0000				
POP PC STACK TO LOW ACCUMULATOR	POP	1011	1110	0011	0001				
CALL SUBROUTINE ADDRESSED BY ACC	1011	1110	0011	0010					
CALL SUBROUTINE ADDRESSED BY ACC DELAYED	CLAD	1011	1110	0011	0011				
TRAP TO LOW VECTOR	TRAP	1011	1110	0011	0100				
TRAP TO LOW VECTOR DELAYED	TRPD	1011	1110	0011	0101				
EMULATOR TRAP TO LOW VECTOR DELAYED	ETRP	1011	1110	0011	0111				
RETURN FROM INTERRUPT	RET1	1011	1110	0011	1000				
RETURN FROM INTERRUPT DELAYED	RTID	1011	1110	0011	1001				
RETURN FROM INTERRUPT WITH ENABLE	RETE	1011	1110	0011	1010				
RETURN FROM INTERRUPT WITH ENABLE DELAYED	TRED	1011	1110	0011	1011				
GLOBAL INTERRUPT ENABLE	EINT	1011	1110	0100	0000				
GLOBAL INTERRUPT DISABLE	DINT	1011	1110	0100	0001				
RESET OVERFLOW MODE	ROVM	1011	1110	0100	0010				
SET OVERFLOW MODE	SOVM	1011	1110	0100	0011				
CONFIGURE BLOCK AS DATA MEMORY	CNFD	1011	1110	0100	0100				
CONFIGURE BLOCK AS PROGRAM MEMORY	CNFP	1011	1110	0100	0101				
RESET SIGN EXTENSION MODE	RSXM	1011	1110	0100	0110				
SET SIGN EXTENSION MODE	SSXM	1011	1110	0100	0111				
SET XF PIN LOW	RXF	1011	1110	0100	0100				
SET XF PIN HIGH	SXF	1011	1110	0100	1101				
RESET CARRY	RC	1011	1110	0100	1110				
SET CARRY	SC	1011	1110	0100	1111				
RESET TC BIT	RTC	1011	1110	0100	1110				
SET TC BIT	STC	1011	1110	0100	1111				
RESET HOLD MODE	RHM	1011	1110	0100	1000				
SET HOLD MODE	SHM	1011	1110	0100	1001				
STORE PRODUCT IN BPR	SPB	1011	1110	0100	1100				
LOAD PRODUCT FROM BPR	LPB	1011	1110	0100	1101				
LONG IMMEDIATES									
MULTIPLY LONG IMMEDIATE BY TREG0	MRKL	1011	1110	1000	0000	IIII	IIII	IIII	IIII
AND WITH ACC LONG IMMEDIATE	ANDK	1011	1110	1000	0001	IIII	IIII	IIII	IIII
OR WITH ACC LONG IMMEDIATE	ORK	1011	1110	1000	0101	IIII	IIII	IIII	IIII
XOR WITH ACCUMULATOR LONG IMMEDIATE	1011	1110	1000	0011	IIII	IIII	IIII	IIII	
REPEAT NEXT SPECIFIED BY LONG IMMEDIATE	PRTR	1011	1110	1000	0100	IIII	IIII	IIII	IIII
CLEAR ACC/PREG AND REPEAT NEXT INST LONG IMMD	RPTZ	1011	1110	1000	0101	IIII	IIII	IIII	IIII
BLOCK REPEAT	RPTB	1011	1110	1000	0110	IIII	IIII	IIII	IIII
SET PREG SHIFT COUNT	SPM	1011	1111	00PM	0000				
LOAD ARP IMMEDIATE	LARP	1011	1111	0ARP	0010				
COMPARE AR WITH CMPR	CMPR	1011	1111	0ARX	0100				
LOAD AR LONG IMMEDIATE	LALK	1011	1111	0ARX	0101				
BARREL SHIFT ACC RIGHT	BSAR	1011	1111	SHIF	1000				
LOAD ACC LONG IMMEDIATE WITH SHIFT	LALK	1011	1111	SHFT	1001	IIII	IIII	IIII	IIII
ADD TO ACC LONG IMMEDIATE	ADLK	1011	1111	SHFT	1011	IIII	IIII	IIII	IIII

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WITH SHIFT									
SUBTRACT FROM ACC LONG IMMEDIATE WITH SHIFT	SBLK	1011	1111	SHFT	1011	IIII	IIII	IIII	IIII
AND WITH ACC LONG IMMEDIATE WITH SHIFT	AMDS	1011	1111	SHFT	1100	IIII	IIII	IIII	IIII
OR WITH ACC LONG IMMEDIATE WITH SHIFT	ORS	1011	1111	SHFT	1101	IIII	IIII	IIII	IIII
XOR WITH ACC LONG IMMEDIATE WITH SHFT	XORS	1011	1111	SHFT	1110	IIII	IIII	IIII	IIII
MULTIPLY TREGO BY 13-BIT IMMEIDATE	MPYK	1101	IIII	IIII	IIII				
BRANCH CONDITIONAL	Bcnd	1110	00TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
EXECUTE NEXT TWO INST ON CONDITION	XC	1110	01TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
CALL CONDITIONAL	CC	1110	10TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
RETURN CONDITIONAL	RETC	1110	11TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
BRANCH CONDITIONAL DELAYED	BconO	1111	00TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
EXECUTE NEXT TWO INST CONDITIONAL DELAYED	ECD	1111	01TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
CALL CONDITIONAL DELAYED	CCD	1111	10TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA
RETURN CONDITIONAL DELAYED	RTCD	1111	11TP	ZLVC	ZLVC	AAAA	AAAA	AAAA	AAAA

Signal Descriptions

SIGNAL	PIN	I/O/Z	DESCRIPTION
			Memory and I/O Interfacing
A15(MSB) A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 A0(LSB)		O/Z	Parrallel address bus A15(MSB) through A0(LSB). Multiplexed to address external data/program memory or I/O. Placed in high-impedance state in hold mode. This signal also goes into high-imedance when OFF-is active low.
D15(MSB) D14 D13 D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 D1 D0(LSB)		I/O/Z	Parallel data bus D15(MSB) throught D0(LSB). Multiplexed to transfer data between the core CPU and external data/program memory or I/O devices. Placed in high-impedance state when not outputting or when RS- or HOLD- is asserted. This signal also goes into high-impedance when OFF-is active low.
DS- PS- IS-		O/Z	Data, program, and I/O space select signals. Always high unless low level adderted for communicating to a particular external space. Placed in his-impedance state in hold mode. These signals also goes into high-immedance when OFF- is active low.
BR-		O/Z	Bus request signal. Asserted when accessing external global bus is available and the global data memory is available for the bus transaction. This signal can also be used to extend the data memory address space by up to 32K words. This signal also goes into high-impedance when OFF- is active low.
READY		I	Data ready input. Indicates that an external device is prepared for the bus transaction to be completed. If the device is not ready (READY is low), the processor waits one cycle and checks READY again. READY also indicates a bus grant to an external device after a BR- (bus request) signal.
R/W-		O/Z	Read/write signal. Indicates transfer direction when communicating to an external device. Normally in read mode (high). unless low level asserted for performing a write operation. Placed in high-impedance state iin hold mode. This signal also

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		goes into high-impedance when OFF- is active low.
STRB-	O/Z	Strobe signal. Always high unless asserted low to indicate an external bus cycle. Placed iin high-impedance state in hthe hold mode. This signal also goes into high-impedance when OFF- is active low.
HOLD-	I	Hold input. This signal is asserted to request control of the address data. and control lines. When acknowledged by the processer, these lines go to a high-impedance state.
HOLDA-	O/Z	Hold acknowledge signal. Indicates to the external circuitry that the processor is in a hold state and its address, data, and memory control lines are in a high impedance state so that they are available to the external circuitry for access of local memory. This signal also goes into high-impedance when OFF- is active low.
MP/MC-	I	Microprocessor/microcomputer mode select pin. If active low at reset (microcomputre mode), the pin causes the internal program memory to be mapped into program memory space. In the microprocessor mode, all program memory is mapped externally. This pin is only sampled during reset and the mode set at reset can be overridden via software control bits.
MSC-	O/Z	Microstate complete signal. This signal indicates the beginning of a new external memory access. The timing of the signal is such that it can be connected back to the READY signal to insert a wait state. This signal also goes iinto high-impedance when OFF- is active low.
		Interrupt and Miscellaneous Signals
BIO-	I	Branch control input. Polled by BIOZ instruction. If low, the device executes a branch. This signal must be active during the BIOZ instruction fetch.
IACK-	O/Z	Interrupt acknowkedge signal. Indicates receipt of an interrupt and that the program is branching to the interrup-vector location indicated by A15-A0. This signal also goes into high-impedance when OFF- is active low.
INT2- INT1- INT0-	I	External user interrupt inputs. Prioritized and maskable by the interrupt mask register and interrupt mode bit. Can be poiled and reset via the interrupt flag register.
RS-	I	Reset input. Causes the device to terminate exectution and forces the program counter to zero. When brought to a high level, execution begins at location zero of program memory. RS- affects various registers and status bits.
XF	O/Z	External flag output (latched software-programmable signal). Used for signalling other processors in multiporcessor configurations or as a general purpose output pin. This signal also goes into high-impedance when OFF- is active low. This pin is set high at reset.
		Supply/Oscillator Signals
CLKOUT1	O/Z	Master clock output signal (CLKIN frequency/4). This signal cycles at half the machine cycle rate and therefore it operates at the instruction cycle rate when operating with one wati state. This signal also goes into high-impedance when OFF- is active low.
CLKOUT2	O/Z	Secondary clock output signal. This signal operates at the same cycle rate as CLKOUT1 but 90 degrees out of phase. This signal also goes into high-impedance when OFF- is active low.
X2/CLKIN	I	Input pin to internal oscillator from the crystal. If the internal oscillator is not being used, a clock may be input to the device on this pin.
X1	O/Z	Output pin from the internal oscillator for the crystal. If the internal oscillator is not used, thsi pin should be left unconnected. This signal also goes into high-impedance when OFF- is active low.
SYNC-	I	Synchronization input. Allows clock synchronization of two or more devices. SYNC- is an active-low signal and must be asserted on the rising edge of CLKIN.
V_{CC1} V_{CC2} V_{CC3} V_{CC4} V_{CC5} V_{CC6} V_{CC7}	Seven 5-V supply pins, tied together externally.	
V_{SS1} V_{SS1} V_{SS1} V_{SS1} V_{SS1} V_{SS1} V_{SS1}	Seven ground pins, tied together externally.	

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Serial Port Signals

CLKR	I	Recieve clock input. External clock signal for clocking data from the DR (data receive) pin into the RSR (serial port receive shift register). Must be present during serial port transfers.
CLKX	I/O	Transmit clock input. External clock signal for clocking data from the XSR (serial port transmit shift register) to the DX (data transmit) pin. Must be present during serial port transfers. This signal can be used as an output operating at one half CLKOUT. This is done by setting the CO bit in the serial port control register.
DR	I	Serial data receive input. Serial data is received in the RSR (serial port received shift register) via the DR pin.
DX	O/Z	Serial port transmit output. Serial data is received in the XSR (serial port transmit shift register) via the DX pin. Placed in high-impedance state when not transmitting. This signal also goes into high-impedance when OFF- is active low.
FSR	I	Frame synchronization pulse for transmit input/output. The failing edge of the FSX pulse initiates the data-transmit process, beginning the clocking of the XSR. Following reset, the default operating condition of FSX is an input. This pin may be selected by software to be an output when the TXM bit in the status register is set to 1. This signal also goes into high-impedance when OFF- is active low.
OFF-	I	Disable all outputs. The OFF- signal, when active low, puts all output drivers in to high-impedance.

BRANCH, CALL and RETURN INSTRUCTIONS

Notes

1. Delayed instructions reduce overhead by not necessitatingg flushing of the pipeline as non-delayed branches do. For example, the two (single-work) instructions following a delayed branch are executed before the branch is taken.
2. All meaningful combinations of the 8 conditions listed below are supported for conditional instructions:

Condition	representation in source
1) ACC = 0	(EQ)
2) ACC < > 0	(NEQ)
3) ACC < 0	(LT)
4) ACC > 0	(GT)
5) OV = 0	(NOV)
6) OV = 1	(OV)
7) C = 0	(C)
8) C = 1	(NC)

For example, execution of the following source statement results in a branch if the accumulator contents are less than or equal to zero and the carry bit is set:

BconD LEQ,C

Note that the conditions associated with BIOZ, BBX, BBNX, BANZ, and BAZD are not combinations of the conditions listed above.

BIT MANIPULATION INSTRUCTIONS

XPL	EXCLUSIVE OR DMBR with data value
OPL	OR DBMR with data value
APL	AND DBMR with data value
CPL	if (data value = DBMR) then TC:=1
XPLK	EXCLUSIVE OR long immediate constant with data value
OPLK	OR long immediate constant with data value
APLK	AND long immediate constant with data value
CPLK	if (long immediate constant = data value) the TC:=1
SPLK	store long immediate constant in data memory
BIT	TC:=bit [4-bit immediate constant] of data value
BITT	TC:=bit[<TREG2>] of data value

Notes

1) Note that the result of a logic operation performed by the PLU is written directly back into data memory, thus not disrupting the contents of the accumulator.

INSTRUCTION INVOLVING ACCB, BPR

Loads/stores

SACR	store ACC in ACCB unconditionally
CRGT	if (ACC > ACCB) then store ACC iin ACCB else ACCB→ACC
CRLT	if (ACC < ACCB) then store ACC iin ACCB else ACCB=ACC
EXAR	exchange ACC with ACCB
LACR	load ACC from ACCB

Additions/subtractions

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ADDR	add ACCB to ACC
ADCR	add ACCB to ACC with carry
AUBR	subtract ACCB from ACC
SBBR	subtract ACCB from ACC with borrow
ABPR	add BPR to accumulator contents
SBPR	subtract BPR from accumulator contents
Logic operations	
ANDR	and ACCB with ACC
ORR	OR ACCB with ACC
XORR	exclusive-or ACCB with ACC

What is claimed is:

1. A digital signal processor comprising:

A. a first data bus carrying first data signals;

B. a first address bus carrying first address signals indicating the address of the first data signals in a first address space;

C. a second data bus separate from the first data bus and carrying second data signals;

D. a second address bus separate from the first address bus and carrying second address signals indicating the address of the second data signals in a second address space;

E. arithmetic and logic circuitry coupled to the first and second data buses, the arithmetic and logic circuitry including multiplier circuitry coupled to an input of an arithmetic and logic unit and an accumulator coupled to an output of the arithmetic and logic unit; and

F. a memory wait state register coupled to the first data bus and the first address bus, the wait state register having plural portions.

2. The processor of claim **1** in which the first address space is segmented into plural portions and a portion of the memory wait state register corresponds to a segment in the first address space.

3. The processor of claim **1** in which the memory wait state register has at least four portions.

4. The processor of claim **1** in which each portion of the memory wait state register contains four bits of information.

5. The processor of claim **1** in which the first data bus is a data bus and the second data bus is an instruction bus.

6. The processor of claim **1** in which each portion of the memory wait state register contains at least three bits of information.

7. The processor of claim **1** in which the memory wait state register is connected to the first data bus to receive wait state data signals from the first data bus.

8. The processor of claim **1** in which the memory wait state register has 16 portions.

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